Urban Stormwater Runoff Water Quality Issues

G. Fred Lee PhD, PE, DEE and Anne Jones-Lee, PhD
G. Fred Lee & Associates
27298 East El Macero Drive
El Macero, CA 95618
www.gfredlee.com email: gfredlee@aol.com

Abstract

Urban stormwater runoff contains heavy metals including copper, lead, and zinc; organics such as pesticides, PAHs, and unidentified compounds; and nutrients (nitrogen and phosphorus) in concentrations that are a threat to cause water quality problems in the waters receiving the runoff. In 1990 the US EPA adopted an urban stormwater runoff water quality management program that requires that municipalities control pollution of receiving waters for runoff to the maximum extent practicable using best management practices (BMPs), and, through a BMP ratcheting-down process, ultimately control violations of water quality standards in the runoff. This regulatory program has several significant problems, including the high cost (dollars/person/day) of treating urban stormwater runoff to control water quality standards violations, and the general ineffectiveness of conventional BMPs for contaminant control. Further, heavy metals and some other potential pollutants in urban stormwater runoff are largely in non-toxic, unavailable forms. There is need for urban stormwater runoff water quality managers to conduct studies to determine the constituents in stormwater runoff that cause significant pollution of the receiving waters. Those constituents that are causing significant water quality use-impairments can potentially be controlled through source control. There is also need to develop wet weather water quality standards to regulate urban stormwater runoff water quality impacts.

Key Words
Urban stormwater runoff, water quality, water quality standards, BMPs, pollution, stormwater

Introduction

Urban creeks and lakes can provide important habitats for aquatic life, as well as aesthetic assets to communities. A key component of this resource is the quality of water in these waterbodies. This chapter is devoted to a review of water quality problems in urban creeks and lakes caused by stormwater runoff-associated pollutants.

The primary function of many urban creeks is the conveyance of stormwater to prevent flooding. Often they have been channelized to assist in achieving rapid removal of stormwater from an urban area. This channelization, coupled with the development (paving) in the urban creek watershed, is at odds with providing high-quality aquatic life habitat. Urban creek flows can vary from a few cubic feet per second of groundwater-based flow to a thousand or more cubic

Invited contribution published as, Lee, G. F., and Jones-Lee, A., "Urban Stormwater Runoff Water Quality Issues," ***Water Encyclopedia: Surface and Agricultural Water****, Wiley, Hoboken, NJ pp 432-437 (2005).*

feet per second during flood flow conditions associated with major runoff events. The high flows are detrimental to developing and 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 provide important aesthetic amenities and, in some cases, recreational fisheries and nursery areas for aquatic life. The fisheries in urban creeks can range from a sustainable trout fishery to carp- or minnow-dominated waters. Some urban lakes provide good warmwater sport fisheries for bass, bluegill, etc.

The Center for Watershed Protection report entitled, "Impacts of Impervious Cover on Aquatic Systems" (CWP, 2003), contains information on some aspects of the impact of urban stormwater runoff on water quality. This 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. 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 this 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. Another source of information on the impact of urban stormwater runoff-associated chemical constituents on water quality is the Stormwater Runoff Water Quality Science/Engineering Newsletter available from www.gfredlee.com.

Regulating Urban Stormwater Runoff Water Quality Impacts

The US EPA (1990) promulgated the national regulations that require cities with populations greater than 100,000 to develop stormwater runoff water pollution control programs to control pollution to the maximum extent practicable (MEP) using best management practices (BMPs). These requirements are also applicable to highway stormwater runoff. The Agency did not define MEP or the BMPs that are to be used. Urban stormwater runoff pollution is to be regulated by National Pollution Discharge Elimination System (NPDES) permits that ultimately require compliance with water quality standards. While NPDES permits for domestic and industrial wastewater discharges are to prevent violations of water quality standards at the point of discharge or at the edge of a mixing zone if provided for, the NPDES permits issued to municipalities for controlling urban stormwater pollution, while requiring ultimately compliance with water quality standards did not specify a date by which compliance with water quality standards is to be achieved. The current regulations require the use of a BMP ratcheting-down process to ultimately, but as of yet at an undefined date, control violations of water quality standards in the runoff. Justification for this difference in approach for regulating urban stormwater runoff, compared with urban wastewater discharges, arises from the significantly different characteristics of urban stormwater runoff.

ASCE (2000) and CASQA (2003) list a variety of "BMPs" that are advocated for the "treatment" of urban stormwater runoff to control water pollution, including ponds that allow settling of some chemical constituents, grassy areas that allow settling and removal of some chemicals, and infiltration basins that allow infiltration of the stormwater into groundwaters. These BMPs were largely based on hydraulic factors without evaluation of their effectiveness in treating stormwater runoff to achieve water quality standards. To the contrary, it has been found that ponds (detention basins), grassy swales, etc. cannot be considered adequate for treating urban stormwater runoff to achieve compliance with water quality standards.

The cost of retrofitting conventional BMPs to developed urban areas has been estimated to be on the order of $1 to $3 per person per day for the population served by the storm sewer collection system. These costs are primarily for the acquisition of land and effectively restrict implementation of these BMPs to new developments where their cost can be incorporated into the cost of the development. While conventional BMPs are being installed especially in new developments, the most popular conventional BMPs will not be adequate to treat urban or highway stormwater runoff to achieve compliance with water quality standards. In order to achieve compliance with water quality standards for urban area and highway stormwater runoff it will be necessary to construct, operate and maintain treatment works of the type used in advanced wastewater treatment. The costs of such retrofitted treatment works in developed areas is projected to be on the order of $5 to $10 per person per day. These very high costs will require that a different approach be developed for regulating urban area stormwater runoff.

Evaluation of Water Quality Impacts of Stormwater Runoff

While there has been considerable work on the chemical characteristics of urban stormwater runoff, little work has been devoted to evaluating the water quality/beneficial use impacts of this runoff. Especially in light of the tremendous costs associated with providing for treatment/ control of stormwater runoff, it is 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 for the development and installation of so-called best managements practices that effect little or no improvement of the beneficial uses of an urban stream or lake or other waterbody receiving the stormwater runoff.

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, as did 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, they 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, 1981).

Heavy Metals. In the fall of 1998, the California Storm Water Quality Task Force conducted a review of constituents that are present in urban area and highway stormwater runoff in sufficient concentrations to cause violations of US EPA water quality criteria and/or California Toxics Rule standards, which were developed by the US EPA (2000) for the state. Copper, lead and zinc were found in almost all urban street and highway stormwater runoff in concentrations that would violate US EPA worst-case-based water quality criteria and state standards based on those criteria. Sometimes cadmium and mercury were also present above those criteria/standards.

These findings indicate that there is a potential for certain heavy metals in urban stormwater runoff to be toxic to aquatic life in urban creeks.

Lee and Taylor (2001a,b) presented the results of a study of heavy metal concentrations and aquatic life toxicity in 10 different Upper Newport Bay (Orange County, California) watersheds during 1999-2000. Several of the watersheds had predominantly urban land use. Lee and Taylor found several heavy metals, including copper, zinc and lead, in concentrations above water quality criteria/standards. Through toxicity identification 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. However, this is not necessarily the case for heavy metals 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 available forms to be toxic to aquatic life.

Aquatic Life Toxicity**.** There are several constituents normally present in urban-area stormwater runoff that could cause aquatic life toxicity. The constituents of greatest concern are the heavy metals, including copper, zinc, lead, and occasionally cadmium. Toxicity measurements of urban stormwater runoff from a number of areas (see Lee et al. 2001a,b and Lee and Taylor 2001b) have shown that although runoff from urban residential and commercial areas may be toxic to *Ceriodaphnia* (a US EPA standard freshwater zooplankton test organism), that toxicity has not been due to heavy metals. Toxicity identification evaluations have shown that the toxicity measured was due to the organophosphorus (OP) pesticides diazinon and/or chlorpyrifos. While 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 typically found in urban runoff.

Pesticide-Caused Toxicity. Lee et al. (2001a,b) reviewed the topic of OP-pesticide-caused toxicity. Diazinon and chlorpyrifos have been, or will soon be, phased out of urban use by the US EPA due to their potential toxicity to children. 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. These OP pesticides are being replaced by others, especially the pyrethroid pesticides, in urban areas. However, the replacement pesticides have not been 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. Further, 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 that is adverse to aquatic life-related beneficial uses of the waterbody.

Dissolved Oxygen. Stormwater runoff events can cause significant dissolved oxygen (DO) depletion in urban streams and other nearby waterbodies. DO measurements made by the DeltaKeeper (2002) in waterbodies just prior to, during and following a runoff event showed that the DO prior to the event was adequate for maintenance of aquatic life – i.e., above about 5 mg/L. However, shortly after the event began, the DO in some of the waterbodies dropped to less than 1 mg/L and stayed depressed for several days. 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 those waterbodies.

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. Kluesener and Lee (1974) and Rast and Lee (1984) determined the nutrient loads associated with urban stormwater runoff. In addition to being derived from stormwater runoff, nutrients, especially nitrate, can also be present in groundwater flow to urban creeks and lakes. This can be an important source of nitrate.

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. Cowen and Lee (1976) conducted studies of the algal available phosphorus in urban stormwater runoff in a number of urban areas. Lee et al. (1980) summarized the results of those studies and those of 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, about 80 percent of the particulate phosphorus (which can be most of the phosphorus load in such runoff) does not support algal growth.

pH. There can be sufficient primary production in urban creeks and lakes to cause significant diel (over a 24-hr day) changes in pH and dissolved oxygen. This is especially true for those urban streams that have only limited areas where extensive canopy from trees along the bank shades the water. The US EPA (1987) Gold Book water quality criterion limits the pH of waters to 9. It is not unusual for the pH of waterbodies to exceed that value in the late afternoon, at the height of photosynthetic activity, and be several units lower in early morning.

Ammonia. It is possible for the ammonia concentrations in urban creeks to be sufficiently high to violate ammonia water quality criteria based on potential toxicity to aquatic life in an urban stream or lake. This is especially likely if there is a significant storm sewer discharge that contains storm sewer-accumulated sludge/sediments scoured during a runoff event, or scour of stream sediments, which would tend to have high ammonia concentrations. The impact of that ammonia would be exacerbated in those urban streams and lakes that are highly productive as they would tend to have an elevated pH in mid-afternoon due to photosynthetic activity.

Sanitary Quality. Especially during dry weather flow, urban stormwater runoff and, in some situations, drainage ways such as creeks in urban areas, often have greatly elevated concentrations of total coliforms, fecal coliforms and *E. coli*. 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*. *E. coli* has become the standard recommended organism for assessing the sanitary quality of a freshwater with respect to contact recreation. It is also a useful indicator of potential pathogens in domestic water supplies. Enterococci have become the standard fecal indicator organism for marine waters. The US EPA (2004) announced that it was implementing its 1986 criteria for those bacteria in states bordering Great Lakes and in ocean waters that had not adopted those criteria by April 2004. In 2005 the US EPA will develop revised contact recreation based water quality criteria for the inland waters of the US.

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 to nearby watercourses on an ongoing basis through leaks in the sewerage system. In addition, animals, including birds, can contribute significant amounts of fecal coliforms and *E. coli* to stormwater runoff, which, in turn, can cause urban creeks to have poor sanitary quality.

With increased emphasis on managing the water quality impacts of urban stormwater runoff in some parts of the country, such as Southern California (especially in the Santa Monica Bay watershed, because of the adverse impacts on sanitary quality of Santa Monica Bay beaches), efforts are being made to control *E. coli* and other pathogen indicators in stormwater runoff, as well as in separate storm sewers during dry weather flow. 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. Information on the current understanding and control of the sanitary quality of urban stormwater runoff is available in the proceedings of the US EPA 2004 national Beaches conference, http://www.epa.gov/beaches/.

Total Organic Carbon (TOC). Based on US EPA regulations, domestic water supplies that have a total organic carbon (TOC) concentrations above about 2 mg/L may be required to treat the water to remove the total organic carbon to that level, in order to reduce the potential for formation of trihalomethanes (THMs) and other disinfection byproducts 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. Site-specific investigations need to be conducted to evaluate this situation for a particular waterbody.

Excessive Bioaccumulation of Hazardous Chemicals in Edible Aquatic Organisms. Fish and other edible aquatic organisms taken from some urban streams have been found to contain excessive concentrations of legacy pesticides such as DDT, dieldrin and chlordane, derived from their former use in urban areas as well as from current runoff from urban areas that had been agricultural. In addition, fish and other aquatic life in urban streams can contain excessive concentrations of PCBs and dioxins/furans. As discussed by Lee and Jones-Lee (2002), dioxins are known to be present in stormwater runoff from urban areas and highways and can, therefore, 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. Some of the edible fish taken from that canal in 1998 contained concentrations of PCBs at levels 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 their bioavailability using the US EPA standard sediment bioavailability test procedure with *Lumbriculus variegatus*. It was found that although 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*. This indicates that those 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. In urban streams or lakes where bioaccumulation of mercury is a potential concern, fish should be examined to determine if they have excessive bioaccumulation of mercury. Lee and Jones-Lee (2002) and Lee (2003) have provided guidance on approaches that should be followed to evaluate excessive mercury bioaccumulation by examination of edible fish tissue.

PAHs, Oil and Grease, and Unrecognized Hazardous/Deleterious Organic Chemicals. There are numerous organic compounds that are not pesticides or organochlorine bioaccumulatable chemicals but are of potential concern in urban stormwater runoff. These include oil and grease, PAHs, and others included in the group of "total organic carbon." Within the oil and grease and TOC fractions in urban stormwater runoff can be thousands of unregulated organic chemicals that pose a threat of toxicity to aquatic life and/or bioaccumulate in edible aquatic life where they pose a threat to higher trophic-level organisms, including humans. Many of these have been in use and entering the environment for many years but have not been regulated. For example, Silva (2003) of the Santa Clara Valley Water District, California has reported that sufficient perchlorate leaches from a flare used at a highway accident, to contaminate 726,000 gallons of drinking water with perchlorate above the California Department of Health Services action level of 4 µg/L.

Daughton (2004) indicated that while there are more than 22 million organic and inorganic substances, with nearly 6 million commercially available, fewer than 200 are addressed by the current water quality regulations. He noted special concern that in general pharmaceuticals and personal care products (PPCPs) are not regulated but can pose significant water quality concerns. Daughton stated, "*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 an urban creek watershed contains areas of new construction and/or if the urban creek watershed and the creek have soils that readily erode, there can be significant increases in suspended solids/turbidity in the creek during runoff events. The increased turbidity makes the water turbid (muddy) which can affect aquatic life habitat.

Trash. Urban creeks are notorious for accumulating materials that people discard, including grocery carts, tires, paper, Christmas trees and shrubbery, and lawn trimmings. While some of these items can inhibit flow and thus lead to flooding, some of this material also provides 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 evidenced 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 pursuant to a TMDL 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**.** As part of its Water Quality Criteria and Standards Plan (US EPA, 1998), the US EPA 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 with the associated increase in impervious cover (e.g., paving) in urban stream watersheds, on the hydrological and morphological characteristics of urban streams. It reported that when the percentage of impervious cover in an urban stream’s watershed exceeds about 10 percent, the stream’s characteristics are typically impacted. When the impervious cover exceeds about 25 percent, there tend to be severe impacts on the waterbody’s characteristics.

As part of the implementation of its Water Quality Criteria and Standards Plan, the US EPA 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 (US EPA, 1998). Thus far the US EPA and state water pollution control agencies seem to have made little progress toward achieving this goal. Information on the US EPA’s current program in this area is presented at http://www.epa.gov/ebtpages/watewaterbioassessment.html.

Overall

It has become evident that there is need for comprehensive 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) receiving 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 US EPA’s announced “Strategy for Water Quality Standards and Criteria” (US EPA, 2003) includes development of wet weather water quality standards. 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.

Lee and Jones-Lee (2003) have reviewed this approach for managing urban area stormwater runoff water quality.

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

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).

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).

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).

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

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

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 (2002). http://www.gfredlee.com/OClTMDLRpt12-11-02.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 (2003). Available on CD ROM from www.ATRP.com. http://www.members.aol.com/duklee2307/PHStormwater-papfinal.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., 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., 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

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).

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

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, "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, "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 (2000).

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. (2004). http://www.epa.gov/beaches/

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).