Stormwater Runoff Water Quality Science/Engineering Newsletter

Devoted to Urban Stormwater-Runoff Water Quality Management Issues

* * * * *

Volume 2 Number 1
October 8, 1

Editor: Anne Jones-Lee, PhD
Contributor to This Issue:
G. Fred Lee, PhD, PE, DEE

* * * * *

Urban Stormwater Runoff Aquatic Life Toxicity

Preface to Newsletter Vol. 2, No. 1

This issue of the Newsletter begins a series of Newsletters that provide additional information on topics covered in Newsletters 5 and 6/7. These past Newsletters covered the potential Water Quality Standards compliance problems that NPDES permitted stormwater management and regulatory agencies face in complying with current US EPA requirements of preventing urban area and highway stormwater runoff associated constituents from causing or contributing to water quality standards violations at the point of stormwater discharge to ambient waters.

One of the characteristics of urban area stormwater runoff that potentially causes water quality standards violations is aquatic life toxicity. Studies in California and elsewhere have demonstrated that urban area stormwater runoff is toxic to certain zooplankton (*Ceriodaphnia* and *Mysidopsis*) that are used as part of the US EPA standard three species toxicity tests. This toxicity is due to the use of the organophosphate pesticides diazinon and chlorpyrifos on residential properties for termite, ant, and lawn/garden pest control. It represents a potential violation of US EPA Clean Water Act requirements of prohibiting the discharge of toxic chemicals in toxic amounts. This toxicity has caused several California Regional Water Quality Control Boards to list certain urban streams as 303(d) impaired waterbodies requiring the development of a total maximum daily load (TMDL) to control the toxicity.

The author and his associates have been involved in a three year study of stormwater runoff aquatic life toxicity in Orange County, California. They have also followed closely the work done in the San Francisco Bay Area and the California Central Valley on the toxicity of urban stormwater runoff. This Newsletter presents a summary of issues that are pertinent to managing the aquatic life toxicity that occurs in urban area stormwater runoff. This Newsletter also provides guidance on the aquatic life toxicity monitoring programs that cities and regulatory agencies should be conducting to determine if urban area stormwater runoff is toxic, the cause of this toxicity with particular reference to the organophosphate pesticides, and approaches that should be used to evaluate the water quality significance of this toxicity.

Background Information

With the US EPA implementation of the 1987 revisions of the Clean Water Act section devoted to urban stormwater runoff impacts on receiving waters for the runoff, the US EPA (1990) established that urban stormwater runoff shall not cause or contribute to violations of water quality standards. This requirement is to be met through a best management practice (BMP) ratcheting down process where the urban stormwater management agencies that hold NPDES stormwater runoff water quality management permits shall implement BMPs to control the water quality standard violations. Stormwater runoff water quality monitoring programs in several areas of California and elsewhere have found that urban stormwater runoff contains several potentially toxic heavy metals, such as lead, copper, zinc, and sometimes cadmium, at concentrations that cause violations of worst case based US EPA water quality criteria/standards at the point of discharge of the stormwater runoff to ambient waters for both total and dissolved forms of the metals.

This is a technical violation of the NPDES permit that could require that the NPDES permit holder initiate BMPs to remove those heavy metals that are present in the stormwater runoff at concentrations above water quality standards at the point of discharge. This is an end of the pipe discharge limitation since in California and in many areas urban stormwater runoff is not allowed a mixing zone. Further, many urban streams are stormwater runoff dominated systems so that the whole stream will have concentrations of certain heavy metals above water quality standards during runoff events.

The US EPA and states require that NPDES permitted discharges shall not contain regulated constituents in toxic amounts. This typically translates to no aquatic life toxicity in NPDES regulated sources. As discussed by Lee and Taylor (1999), urban stormwater runoff in several California cities, including Sacramento, Stockton, Los Angeles, San Diego, and communities in the San Francisco Bay region and Orange County, California, and elsewhere such as Fort Worth, Texas (Waller *et al*. 1995) has been found to be toxic to *Ceriodaphnia dubia*. While initially it was suggested that this toxicity was due to heavy metals in the stormwater runoff, it has been repeatedly found (Hansen & Associates 1995, and others, see Lee and Taylor 1999) that it is due to the organophosphate pesticides diazinon and chlorpyrifos (Dursban) that are used in urban areas for structural termite, ant, and lawn/garden pest control. In some areas, such as Orange County, California, over 100,000 pounds of active ingredient diazinon and chlorpyrifos are used each year on residential properties with most of the use for structural pest control (Lee and Taylor 1997).

This situation is not restricted to California and Texas where urban stormwater runoff toxicity due to OP pesticides has been well documented. These pesticides are used throughout the US and are likely causing urban stormwater runoff to be toxic to some forms of freshwater zooplankton such as *Ceriodaphnia* and marine zooplankton such as *Mysidopsis bahia* in most urban stormwater runoff flow dominated streams and receiving waters. These zooplankton are similar to the pests that the pesticides are designed to control and therefore are highly susceptible to OP pesticide toxicity.

As recently discussed by Lee and Taylor (1999), the urban stormwater runoff toxicity studies conducted in several areas have found that typically the heavy metals in urban stormwater runoff from urban area streets and highways are in non toxic forms and, therefore, the exceedance of the water quality standard by the heavy metal is an administrative exceedance that relates to the approach that states use in implementing US EPA worst case based national water quality criteria such as the "Goldbook" criteria (US EPA 1987a), as well as the US EPA (1996) updates of several of these criteria, and include exceedance of the US EPA (1997) proposed California Toxics Rule criteria (US EPA 1997) for dissolved heavy metals. An administrative exceedance exists when exceedance of water quality criteria/standards occurs under conditions where the constituent(s) responsible is in a non-toxic, non-available form, as well as when the duration of exposure of aquatic life to toxic available forms of the constituent(s) is less than the critical exposure required to be adverse to the organism.

Based on current information, the toxicity of the OP pesticides in urban stormwater runoff is largely restricted to certain cladacerans zooplankton (small animals) and the amphipod Gammarus. The concentrations of OP pesticides found in urban stormwater runoff are typically on the order of a few hundred nanograms/L (ng/L). The LC_{50} for diazinon to *Ceriodaphnia* is about 450 ng/L. The LC_{50} for chlorpyrifos to *Ceriodaphnia* is about 80 ng/L, while the LC_{50} for chlorpyrifos to *Mysidopsis* is about 35 ng/L. Neither pesticide is normally present in urban stormwater runoff at concentrations that are toxic to fish larva or algae. This means that in order for this toxicity to be adverse to fish and other higher trophic level forms of aquatic life, the OP pesticide sensitive zooplankton must be key components of the larva fish food at a critical period of the year.

Diazinon and chlorpyrifos are widely used as agricultural pesticides. Several studies in California have found high levels of *Ceriodaphnia* toxicity in agricultural stormwater runoff and irrigation tail (return) waters. This is a particularly important problem in the Central Valley of California where large amounts of diazinon are used each winter as a dormant spray in orchards. This use leads to major rivers, such as the Sacramento and San Joaquin Rivers and the Delta formed by these rivers in California, to be toxic to *Ceriodaphnia* for several weeks each year (Kuivula and Foe 1995). As discussed below, several probabilistic ecological risk assessments have been published, Novartis (1997) and Giesy *et al*. (1999), which purport to show that this toxicity is not likely to be of major ecological significance because of the limited numbers of types of organisms affected and the potential that those organisms with OP pesticide sensitivity similar to *Ceriodaphnia* and *Mysidopsis* are not essential components of the ecosystem food web.

In many urban areas where OP pesticide caused aquatic life toxicity is found, the total toxicity can largely be accounted for by the concentrations of diazinon and chlorpyrifos. In some areas, such as Orange County, California, stormwater runoff contains large amounts of unknown caused toxicity to *Ceriodaphnia* and *Mysidopsis*. Based on a three year study of San Diego Creek as it enters Upper Newport Bay, Orange County, California, stormwater runoff contains from 8 to 30 24-hr acute toxic units of *Ceriodaphnia/Mysidopsis* toxicity where only about half of the toxicity can be accounted for based on the concentrations of diazinon and chlorpyrifos. The remainder of the toxicity is due to yet unidentified causes. This toxicity is not due to metals and does not appear to be due to other commonly measured OP and carbamate pesticides. Also, based on piperonyl butoxide (PBO) activation, it does not appear to be due to pyrithroid pesticides. There are chemicals present in stormwater runoff in the Orange County area that are highly toxic to *Ceriodaphnia* and *Mysidopsis* that thus far have not been identified. The stormwater runoff in Orange County, as it enters Upper Newport Bay, is derived from urban, agricultural, and commercial nursery discharges. It appears that all three sources are responsible for some of the unknown caused toxicity (Lee and Taylor 1999).

Regulation of OP Pesticide Caused Aquatic Life Toxicity

As discussed by Lee *et al*. (1999), the finding of OP pesticide caused aquatic life toxicity associated with the use of these pesticides in agricultural and urban areas has caused regulatory agencies in California to list several waterbodies on the 303(d) list of impaired waterbodies. This in turn requires that TMDLs be developed to control the OP pesticides diazinon and chlorpyrifos and their associated aquatic life toxicity. Several California Regional Water Quality Control Boards are developing TMDLs for diazinon and chlorpyrifos and OP pesticide caused aquatic life toxicity to *Ceriodaphnia*. However, there is considerable controversy about the TMDL goal that should be used. This controversy stems from the fact that the US EPA Office of Pesticide Programs (US EPA OPP) requirements for control of the adverse impacts of pesticides to non target organisms allows toxicity to aquatic life, provided that this toxicity is not significantly adverse to the beneficial uses of the waterbody. While the Clean Water Act requires the control of all aquatic life toxicity, for pesticides, before the registered use of a pesticide can be restricted, it must be shown to be significantly adverse to public health or the environment. Because of the conflict between Clean Water Act (no toxics in toxic amounts) and US EPA OPP (no toxicity that is significantly adverse to beneficial uses) it is not clear how the OP pesticide caused aquatic life toxicity in urban and agricultural stormwater runoff will be regulated.

Figure 1 shows the OP pesticide toxicity impact evaluation situation that exists in Orange County, California. As discussed by Lee *et al*. (1999), in order for the OP pesticide caused toxicity in the stormwater runoff to be significantly adverse to the Upper Newport Bay aquatic ecosystem, a marine zooplankton must migrate to the mixed non-toxic marine/toxic fresh water lens and stay in this water for a sufficient period of time to receive a critical exposure. Further the zooplankton that are killed must be an essential, non-replaceable component of the larva fish diet that are considered by the public to be imp ortan t.

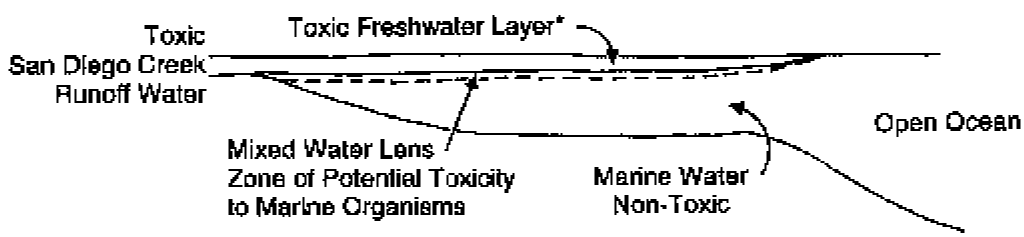

Figure 1 - Stormwater Runoff Aquatic Life Toxicity Situation in Upper Newport Bay, Orange County California

For urban streams, the travel time from the headwaters to the discharge to larger waterbodies is often short compared to the critical exposure that is needed to be adverse to the zooplankton which move with the water during a runoff event. At this time there are no guidelines on how regulatory agencies and others should evaluate what the killing of certain zooplankton by OP pesticides associated with stormwater runoff events means to higher trophic level organisms of concern to the public

The OP pesticide caused aquatic life toxicity associated with urban storm water runoff is typically associated with one to two units of acute *Ceriodaphnia* toxicity that last a day or so during the stormwater runoff event. Further, in many situations the toxic urban stormwater runoff is rapidly diluted below toxic levels in the receiving waterbody such as a river, lake, estuary, or marine waterbody. Therefore the potential area of impact for the OP pesticide caused toxicity is largely restricted to urban streams which in many cases are channelized to control flooding. While these waterbodies beneficial uses are often classified as aquatic life habitat, the quality of this habitat is often severely degraded. It is questionable whether the elimination of the OP pesticide caused aquatic life toxicity, that is found when the US EPA standard *Ceriodaphnia* toxicity test is used, will have a significant impact on the fisheries related beneficial uses of urban streams.

An aspect of the regulation of OP pesticide caused aquatic life toxicity that needs to be considered is that there are other pesticides available, such as the pyrithroids, that can provide about the same pest control as the diazinon and chlorpyrifos. These pesticides are also highly toxic to some forms of zooplankton. The current regulatory approach covering the registration and use of pesticides does not require that a potential environmental impact evaluation be made before substituting one pesticide for another. It is evident that there is need to significantly improve the pesticide registration process to screen pesticides for potential impact on lower trophic level organisms such as *Ceriodaphnia*.

Water Quality Criteria/Standards for Diazinon and Chlorpyrifos

Currently, the US water pollution control programs are largely focused on the development of TMDLs for regulated constituents that are present at concentrations above water quality standards. One of the fundamental aspects of developing a TMDL for diazinon and/or chlorpyrifos is the selection of a target value which can serve as the goal of the TMDL. Typically, the TMDL goal is the elimination of the 303(d) impaired listing of a waterbody due to a particular chemical. The 303(d) listings frequently arise out of the exceedance of numeric or narrative water quality standards. While, in the early 1980s, the US EPA (1987a) developed a water quality criterion for chlorpyrifos, since chlorpyrifos is not listed as a toxic pollutant in the National Toxics Rule, states are not required to adopt this criterion as a state standard. The State of California Water Resources Control Board has not adopted this criterion as a state standard and therefore, the regulation of the chlorpyrifos caused toxicity is not subject to the same regulatory requirements as exist for heavy metals and other potentially toxic constituents that have water quality standards.

The US EPA freshwater acute water quality criterion for chlorpyrifos is 70 ng/L, which is to be implemented on a one-hour average. The US EPA freshwater chronic criterion for chlorpyrifos is 41 ng/L, which is to be implemented on a four-day average. The corresponding US EPA criteria for salt water are acute 56 ng/L and chronic 30 ng/L. A review of the data obtained in the Orange County study (see Lee *et al* 1999, Lee and Taylor 1999) shows that chlorpyrifos is frequently present in San Diego Creek or its tributaries at concentrations above the US EPA chronic and acute water quality criteria. Since there is a US EPA criterion value established for chlorpyrifos, it is likely that this value will become the TMDL goal.

With respect to stormwater runoff conditions, it is unlikely that the chronic criterion (based on a four-day average) would be exceeded for urban area stormwater runoff. However, the acute criterion value for both fresh and marine waters based on a one-hour average will frequently be exceeded in San Diego Creek in various parts of the watershed and as it enters Upper Newport Bay.

The US EPA has been developing a water quality criterion for diazinon since the late 1980s. The US EPA under contract with the University of Wisconsin Superior (1998), has developed a draft acute water quality criterion for diazinon; however, it has not been able to develop a chronic criterion. The California Department of Fish and Game (DFG), using US EPA water quality criteria development approaches (US EPA, 1987b), has developed suggested water quality criteria for diazinon and chlorpyrifos (Menconi and Cox 1994; Menconi and Paul 1994). For chlorpyrifos, the DFG freshwater chronic suggested criterion is 20 ng/L, and salt water chronic suggested criterion is 10 ng/L. These values are similar to the US EPA (1987a) water quality criteria for chlorpyrifos.

For diazinon, the DFG freshwater acute suggested criterion is 80 ng/L, and the chronic suggested criterion is 40 ng/L. DFG did not develop a salt water criterion for diazinon, evidently because thus far no marine organism has been found to be highly sensitive to this pesticide. The concentrations of diazinon found in the Upper Newport Bay watershed studies by Lee and Taylor (1999) in San Diego Creek and its tributaries are typically above the DFG suggested acute water quality criterion.

Ecological Risk Assessment as a Regulatory Approach.

Novartis (1997) and Giesy *et al*. (1999), on behalf of Dow AgroSciences have developed probabilistic risk assessments for assessing the water quality significance of *Ceriodaphnia* toxicity associated with the use of the OP pesticides diazinon and chlorpyrifos. These risk assessments purport to show that, based on the information available, there is a potential impact of OP pesticide toxicity derived from agricultural runoff on aquatic life resources of a waterbody. However, this impact is within the promoted level of aquatic life toxicity that is claimed to be acceptable, i.e., 10% of the species within a waterbody can be killed 10% of the time without significant adverse impact on ecosystem functioning (SETAC 1994). The OP pesticide ecological risk assessment work that has been done thus far confirms what was known from the exceedance of a water quality standard approach, that there are potentially significant water quality problems associated with the OP pesticide aquatic life toxicity that need to be better understood before it can be concluded that this toxicity is not significantly detrimental to the designated beneficial uses of a waterbody.

Further, such issues as additive and synergistic effects of various toxicants, including other OP pesticides, are thus far ignored in the probabilistic risk assessments that have been conducted. Basically, the probabilistic risk assessment shows that the cladoceran *Ceriodaphnia* is highly sensitive to OP pesticide toxicity. It is not, however, the most sensitive organism known. The amphipod *Gammarus fasciatus* is about twice as sensitive to diazinon toxicity as *Ceriodaphnia dubia* (Novartis 1997). A similar situation exists with respect to chlorpyrifos, where the amphipod *Gammarus fasciatus* is about twice as sensitive to chlorpyrifos as some cladocerans Giesy *et al*. (1999). There is potential, through further study, that other organisms will be found to have even greater sensitivity to diazinon and chlorpyrifos toxicity than *Ceriodaphnia*. While these OP pesticides are apparently not toxic to higher trophic level aquatic life, such as fish larvae, there is need to better understand the ecological role of cladocerans such as *Ceriodaphnia* and amphipods in providing food for key higher trophic-level aquatic organisms of concern to the public.

While an ecological risk assessment is an interesting initial step in an evaluation of the potential water quality significance of OP pesticide toxicity, at this time ecological risk assessment falls far short of providing the information needed to assert that the toxic pulses caused by OP pesticides that occur in receiving waters for urban area and some agricultural area stormwater runoff are not adverse to key aquatic organisms of concern to the public. Further, and most importantly, as discussed by Solomon (1996), the ecological risk assessment approach places a great demand for high quality data far beyond that available on the potential impacts of the OP pesticides on the aquatic ecosystem and water quality.

Recommended Urban Stormwater Runoff OP Pesticide Toxicity Monitoring Program

Presented below is a recommended urban area stormwater runoff aquatic life toxicity monitoring program. This program was developed by Lee (1999).

Monitoring for Aquatic Life Toxicity

Urban stormwater runoff should be monitored using standard US EPA aquatic life toxicity testing procedures (Lewis *et al.*, 1994; US EPA, 1994, 1995). These procedures have been used at the University of California, Davis, the Central Valley Regional Water Quality Control Board for *Ceriodaphnia* testing, and at Pacific Eco-Risk Laboratories, Martinez, California, for mysid toxicity testing for urban stormwater runoff. Additional information on these procedures is provided by Bailey *et al.* (1996), Deanovic *et al.* (1998a,b), and Foe *et al.* (1998). The Lee *et al.* (1999a) Upper Newport Bay study QAP Plan consists primarily of the University of California, Davis procedures for *Ceriodaphnia* testing and the Pacific Eco-Risk Laboratories procedures for mysid testing.

Use Adequate Sensitivity for OP Pesticide Measurement

It is important to measure diazinon and chlorpyrifos with adequate sensitivity to detect their presence at potentially toxic levels. The University of California, Davis Aquatic Toxicology Laboratory has been using ELISA procedures which have a detection limit for diazinon of about 30 ng/L and for chlorpyrifos of about 50 ng/L. Occasionally, split samples between laboratories have been analyzed where reasonably good agreement between two different labs, sometimes using different ELISA testing reagents and reagent sources, has been obtained. Also, good agreement has been achieved with an independent dual column GC analysis conducted by Appl Lab, Fresno, CA. Appl is using standard US EPA 8141 Special Low-Level gas chromatographic procedures with an increased evaporation step in order to achieve higher sensitivity.

Assessment of Total Toxic Units and OP Pesticide Toxicity

In addition to measuring total toxicity to *Ceriodaphnia* and mysids, where toxicity is found, a dilution series with or without PBO should be conducted (Bailey *et al*, 1996; Deanovic *et al.*, 1998b; Lee and Taylor, 1997, 1999; Foe *et al.*, 1998). This additional toxicity testing determines the magnitude of the toxicity, i.e. how many toxic units are present and whether the toxicity is likely due to an organophosphate pesticide (diazinon or chlorpyrifos). A dilution series consisting of 100%, 50%, 33%, 25%, 20%, 16.6%, 12.5% and, for highly toxic samples, 6.25% of the stormwater runoff should be tested. These tests should be run with and without PBO at 100 : g/L. The inclusion of PBO in some of the test samples is part of a directed TIE procedure designed to determine whether the toxicity found is likely due to an OP pesticide.

There are a number of commercial laboratories that can reliably conduct aquatic life toxicity testing. In addition to using the University of California, Davis Aquatic Toxicology Lab in the Upper Newport Bay studies, Lee and Taylor (1999) have been using Pacific Eco-Risk of Martinez, California (Scott Ogle) and *Aqua*-Science of Davis, California (Jeff Miller).

Seasonal Sampling

The stormwater sampling should be done for the first significant (>0.3 inch) rainfall event of the fall at the point where the stormwater runoff enters the receiving waters of concern. In addition, it is desirable to have a mid-winter sample and especially a late spring sample. If there is a base flow of water into the receiving waters during non-runoff events, then dry weather flow samples should be taken during the summer and fall/winter.

It is also recommended that at least for the fall stormwater runoff sample, toxicity testing be done using fathead minnow larvae and algae following the US EPA procedures of Lewis *et al.* (1994).

Identification of the Source of Toxicity

If toxicity is found, then a forensic (Toxicity Reduction Evaluation, TRE) study should be conducted through the use of a combination of toxicity measurements and chemical analyses to determine the source of the toxicity within the watershed. Lee and Taylor (1999) provide an example of this approach. While the urban stormwater runoff *Ceriodaphnia* toxicity appears in many areas to be due to the residential use of diazinon and chlorpyrifos, there can also be other significant sources of OP pesticides and *Ceriodaphnia* toxicity. For example, in the Lee and Taylor (1999) work in Orange County, it was found that commercial nurseries located in the Upper Newport Bay/San Diego Creek watershed are major sources of diazinon and unknown-caused toxicity.

Based on the work of Scanlin (1997) and Lee (1998b), it has been found that the use of OP pesticides in accord with the registration label causes stormwater and fugitive water runoff from residential properties to be toxic to *Ceriodaphnia*. There can be little doubt that the use of these OP pesticides on lawns and residential shrubbery can lead to stormwater runoff *Ceriodaphnia* toxicity. An issue that needs to be addressed is whether the use of these and other pesticides for termite and ant control, where the pesticides are injected below the surface, leads to stormwater and fugitive water runoff *Ceriodaphnia* toxicity. This is an area that needs attention as part of developing a regulatory program for the OP pesticide *Ceriodaphnia* toxicity.

Thus far, the work on OP pesticide caused toxicity has focused on diazinon and chlorpyrifos. There are other OP pesticides used in residential areas for structural pest control that could be responsible for part of the *Ceriodaphnia* toxicity. For example, approximately 5,000 pounds of propetamphos was used in Orange County in 1997 for residential structural pest control. Propetamphos is an OP pesticide that can only be used by commercial applicators. The ELISA testing procedures, as well as the gas chromatographic procedures normally used, do not detect the presence of this pesticide.

If four or more units of unknown (cannot be accounted for based on the use of PBO and ELISA testing) caused toxicity are found in the samples, then US EPA Toxicity Identification Evaluation (TIE) procedures should be followed to determine the cause of this toxicity (US EPA, 1989a,b, 1991, 1992; Deanovic *et al.*, 1998b; Foe *et al.*, 1998). It may be necessary to use some of the new TIE techniques, such as Miller *et al.* (1997), and Kuivila and Crepau (1999) to identify the cause of the *Ceriodaphnia* toxicity. It is possible, as found in the Orange County studies, that standard TIEs may not be able to determine the specific chemicals responsible for the toxicity. Under these conditions it is appropriate to use forensic studies to determine the source of the unknown caused toxicity in the watershed. This could lead to control programs without having to spend large amounts of money in Phase IV TIEs determining the cause of the toxicity.

Agriculture as a Source of Urban Pesticides

While urban use of diazinon and chlorpyrifos for residential structural and lawn/garden pest control appears to be the primary source of diazinon and chlorpyrifos toxicity in urban stormwater runoff (Scanlin, 1997), there can be situations such as those reported by Connor (1995) where agriculturally applied diazinon can cause rainfall and fogfall to be toxic to *Ceriodaphnia* at considerable distances from the point of application. This is the result of airborne transport of this pesticide associated with its use in the winter as a dormant spray in orchards. Also, upstream agricultural uses of diazinon and chlorpyrifos can cause *Ceriodaphnia* toxicity (Foe, 1995; Kuivila, 1993; Kuivila and Foe, 1995; USGS, 1993; Deanovic *et al.*, 1998a; Foe *et al.*, 1998; Panshin *et al.*, 1998).

Assessing the Water Quality Significance of the OP Pesticide Toxicity

In addition to determining if the stormwater runoff is toxic as it enters the receiving water, there is need to determine the fate of this toxicity in the receiving waters for the stormwater runoff. Site-specific receiving water studies should be conducted to determine the magnitude, areal extent, and persistence of chlorpyrifos, diazinon and total toxicity in these waters (Lee and Taylor, 1999). This information is essential to assessing whether the OP pesticide toxicity found in urban stormwater runoff is significantly adverse to the designated beneficial uses of the receiving waters for the stormwater runoff.

References

Bailey, H.C., DiGiorgio, C. and Kroll, K. "Development of Procedures for Identifying Pesticide Toxicity in Ambient Waters: Carbofuran, Diazinon, Chlorpyrifos," *Environmental Toxicology and Chemistry*, 15(6):837-845 (1996).

Connor, V. "Pesticide Toxicity in Urban Storm Runoff." Presentation to the Central Valley Regional Water Quality Control Board. Sacramento, CA. June (1995).

Deanovic, L., Larsen, K., Cortright, K., Hinton, D.E., Connor, V. "Sacramento River Watershed Program Toxicity Testing Results, Quarterly Report, January-February 1998" Prepared for the Sacramento Regional County Sanitation District, University of California, Davis, Aquatic Toxicology Laboratory, Davis, CA, and the Central Valley Regional Water Quality Control Board, Sacramento, CA, April (1998a).

Deanovic, L., Cortright, K., Larsen, K., Bailey, H., Hinton, D.E., Connor, V. "Guidelines for Conducting Toxicity Identification Evaluation Procedures in Urban Runoff, a Laboratory Manual," Prepared for the Central Valley Regional Water Quality Control Board, University of California, Davis, Aquatic Toxicology Laboratory, Davis, CA, June (1998b).

de Vlaming, V. "Are the Results of Single Species Toxicity Tests Reliable Predictors of Aquatic Ecosystem Community Responses? A Review," In: Report "Monitoring and Assessment," Unit Division of Water Quality, State Water Resources Control Board, Sacramento, CA (1995).

de Vlaming, V. and Norberg-King, T. "A review of Single Species Toxicity Tests: Are the Tests Reliable Predictors of Aquatic Ecosystem Community Responses," US EPA (1999, in press).

Foe, C. "Insecticide Concentrations and Invertebrate Bioassay Mortality in Agricultural Return Water From the San Joaquin Basin," Central Valley Regional Water Quality Control Board, Sacramento, CA, December (1995).

Foe, C., Deanovic, L., and Hinton, D. "Toxicity Identification Evaluation of Orchard Dormant Spray Storm Runoff," California Regional Water Quality Control Board Central Valley Region, Sacramento, CA, and University of California, Davis, Aquatic Toxicology Laboratory, Davis, CA, November (1998).

Giesy, J.P., Solomon, K.R., Coats, J.R., Dixon, K., Giddings, J., Kenaga, E., "Chlorpyrifos: Ecological Risk Assessment in North American Aquatic Environments," Reviews of Environmental Contamination and Toxicology, 160: 1-129, Springer, New York, NY (1999).

Grothe, D.R., Dickson, K.L. and Reed-Judkins, D.K. Whole Effluent Toxicity Testing: An Evaluation of Methods and Prediction of Receiving System Impacts, SETAC Press Pensacola, FL (1996).

Hansen & Associates. "Identification and Control of Toxicity in Storm Water Discharges to Urban Creeks, Final Report," Prepared for Alameda County Urban Runoff Clean Water Program, Hayward, CA, March (1995).

Jones-Lee, A. and Lee, G.F. "Evaluation Monitoring as an Alternative to Conventional Water Quality Monitoring for Water Quality Characterization/ Management," In: Proc. of National Water Monitoring Conference, "Monitoring: Critical Foundations to Protect Our Waters," US Environmental Protection Agency, Washington, DC, pp.499-512 (1998).

Katznelson, R. and Mumley, T. "Diazinon in Surface Waters in the San Francisco Bay Area: Occurrence and Potential Impact," Report to California State Water Resources Control Board and Alameda Countywide Clean Water Program, Oakland, CA, June (1997).

Kuivila, K.M. "Diazinon Concentrations in the Sacramento and San Joaquin Rivers and San Francisco Bay, California, February 1993," Open-File Report 93-440, Water Facts Sheet, US Geological Survey, Sacramento, CA (1993).

Kuivila, K.M. and Foe, C.G. "Concentrations, Transport and Biological Effects of Dormant Spray Pesticides in the San Francisco Estuary, California," *Environmental Toxicology and Chemistry*, 14:1141-1150 (1995).

Kuivila, K.M. and Crepau, K.L. "Laboratory Study of the Response of Select Insecticides to Toxicity Identification Evaluation Procedures," US Geological Survey, Water-Resources Investigations Report; 99-XXXX, Sacramento, CA (1999). In Press.

Larsen, K. "Sacramento River Watershed Project Toxicity Monitoring Results: 1996-97," Prepared for the Regional Water Quality Control Board, Sacramento, CA, June (1998).

Larsen, K. "Sacramento River Watershed Project Toxicity Monitoring Results: 1997-98, Final Report," Prepared for the Sacramento Regional County Sanitation District, University of California, Davis, Aquatic Toxicology Laboratory, Davis, CA, November (1998).

Larsen, K., Deanovic, L., Hinton, D.E., Connor, V. "Sacramento River Watershed Program Toxicity Testing Results, Quarterly Report: March-May 1998," Prepared for the Sacramento Regional County Sanitation District, University of California, Davis, Aquatic Toxicology Laboratory, Davis, CA, and the Central Valley Regional Water Quality Control Board, Sacramento, CA, June (1998).

Lee, G.F. "Report of Aquatic Life Toxicity for the Los Angeles County Stormwater Runoff Samples Collected on March 25, 1998," Report G. Fred Lee & Associates, El Macero, CA, December (1998a).

Lee, G.F. "Investigation of OP Pesticide Toxicity in Runoff From a Residential Property," Report G. Fred Lee & Associates, El Macero, CA, (1998b).

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)

Lee, G.F. and Jones-Lee, A. "Development of Regulatory Approach for OP Pesticide Toxicity," Presented at NorCal SETAC meeting, Reno, NV (1998).

Lee, G. F. and Taylor, S., "Aquatic Life Toxicity in Stormwater Runoff to Upper Newport Bay, Orange County, California: Initial Results," Report to Silverado, Irvine, CA submitted by G. Fred Lee & Associates, El Macero, CA (1997).

Lee, G.F., Taylor, S., "Results of Aquatic Life Toxicity Studies Conducted During 1997-98 in the Upper Newport Bay Watershed", Review of Existing Water Quality Characteristics of Upper Newport Bay, Orange County CA and its Watershed, Report 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 205(j) Project, G. Fred Lee & Associates, El Macero, California, Robert Bean William Frost & Associates, Irvine, California, October (1999).

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 (1999) in press, preprint available from www.gfredlee.com.

Lewis, P. A., Klemm, D. J., Lazorchack, J .M., Norberg-King, T., Peltier, W. H. and Heber, M. A, "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms," Environmental Monitoring Systems Laboratory, Cincinnati, OH; Environmental Research Laboratory, Duluth, MN; Region 4, Environmental Services Division, Athens, GA; Office of Water, Washington, D.C.; Environmental Monitoring Systems Laboratory, Cincinnati, OH; Office of Research and Development, US Environmental Protection Agency, Cincinnati, OH (1994).

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

Menconi, M. and Paul, A., "Hazard Assessment of the Insecticide Chlorpyrifos to Aquatic Organisms in the Sacramento-San Joaquin River System," Department of Fish and Game, Environmental Services Division, Pesticide Investigations Unit, Administrative Report 94-1, Rancho Cordova, CA (1994).

Miller, J.L., M.J. Miller, V. de Vlaming, and C. Foe, "Selective Removal of Diazinon and Chlorpyrifos from Aqueous Matrices Using Antibody-Mediated Chemical-Specific Procedures," 18th Annual Meeting, Society of Environmental Toxicology and Chemistry. San Francisco, CA, (1997). Abstract.

Novartis, "An Ecological Risk Assessment of Diazinon in the Sacramento and San Joaquin River Basins," Novartis Crop Protection, Inc., Technical Report: 11/97, Greensboro, NC (1997).

Panshin, S.Y., Dubrovsky, N.M., Gronberg, J.M., Domagalski, J.L., "Occurrence and Distribution of Dissolved Pesticides in the San Joaquin River Basin, California," US Geological Survey, Water-Resources Investigations Report 98-4032, National Water-Quality Assessment Program, Sacramento, CA, (1998).

Scanlin, J., "Characterization of Insecticide Use and Presence in the Castro Valley Creek Watershed Draft Report," Alameda County Flood Control and Water Conservation District, Oakland, CA (1997).

SETAC (Society of Environmental Toxicology and Chemistry), Aquatic Risk Assessment and Mitigation Dialogue Workgroup, Final Report, SETAC Foundation for Environmental Education, Inc., Pensacola, FL (1994)

Silverado, "Drainage Report, Evaluation Monitoring Demonstration Project, Phase I," Report of Silverado Constructors, Irvine, CA submitted to Transportation Corridor Agencies Orange County, CA, September 17 (1997).

Solomon, K.R., "Overview of Recent Developments in Ecotoxicological Risk Assessment," Risk Analysis, Vol. 16:627-633 (1996)

University of Wisconsin-Superior, "Draft Ambient Aquatic Life Water Quality Criteria: Diazinon," prepared for US EPA Office of Water, Washington, DC. (1998)

US EPA, "Water Quality Criterion for Chlorpyrifos" in Quality Criteria for Water 1986, US Environmental Protection Agency, EPA 440/5086-001, Office of Water Regulations and Standards, Washington, D.C. (1987a).

US EPA, "Quality Criteria for Water 1986," US Environmental Protection Agency, EPA 440/5086-001, Office of Water Regulations and Standards, Washington, D.C. (1987b).

US EPA, "Methods for Aquatic Toxicity Identification Evaluations: Phase II Toxicity Identification Procedures," US Environmental Protection Agency, EPA/600/3-88/035. Environmental Research Laboratory, Duluth, MN, (1989a).

US EPA, "Methods for Aquatic Toxicity Identification Evaluations: Phase III Toxicity Confirmation Procedures", US Environmental Protection Agency, EPA/600/3-88/036. Environmental Research Laboratory, Duluth, MN, (1989b).

US EPA, "Methods for Aquatic Toxicity Identification Evaluations: Phase I Toxicity Characterization Procedures," Second Edition, Norberg-King, T.J., Mount, D.I. et al (eds.)US Environmental Protection Agency, EPA/600/6-91/003. Environmental Research Laboratory, Office of Research and Development, Duluth, MN, (1991).

US EPA, "Toxicity Identification Evaluation: Characterization of Chronically Toxic Effluents, Phase I," US Environmental Protection Agency, EPA/600/6-91/005F. Environmental Research Laboratory, Office of Research and Development, Duluth, MN, (1992).

US EPA, "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms. Second Edition," US Environmental Protection Agency, EPA-600-4-91-003, Cincinnati, OH (1994).

US EPA. "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to West Coast Marine and Estuarine Organisms, First Edition," US Environmental Protection Agency, EPA/600/R-95/136, Environmental Research Laboratory, Cincinnati, OH (1995).

US EPA, "1995 Updates: Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water," US Environmental Protection Agency, EPA-820-B-96-001, Office of Water, Washington, D.C. (1996).

US EPA, "Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Proposed Rule," *Federal Register*, 40 CFR Part 131, US Environmental Protection Agency, Washington, D.C., August 5 (1997).

USGS. "Diazinon Concentrations in the Sacramento and San Joaquin Rivers and San Francisco Bay, California, February 1993," Water Fact Sheet, Open File Report 93-440, US Geological Survey, Department of the Interior, Sacramento, CA (1993).

Waller, W.T., Acevedo, M.F., Morgan, E.L., Dickson, K.L., Kennedy, J.H., Ammann, L.P., Allen, H.J. and Keating, P.R. "Biological and Chemical Testing in Storm Water," In: Stormwater NPDES Related Monitoring Needs, H. C. Torno (ed.), Proc. Engineering Foundation Conference, August 1994, ASCE, New York, pp. 177-193, (1995).

The section on the probabilistic risk assessment was originally published in part in NorCal SETAC News Timely Topics Summer, 1999.Organophosphate Pesticides, Diazinon and Chlorpyrifos as Urban Stormwater Toxicants