The Sacramento River Watershed Program OP Pesticide Focus Group is initiating several best management practice (BMP) evaluation projects to determine their efficacy in controlling diazinon export from dormant sprayed orchards. At the last OP Focus Group meeting, mention was made that there was interest in having the Focus Group Monitoring workgroup provide assistance to the several different projects that are involved in evaluating stormwater runoff diazinon BMP efficacy. In connection with this request, there are several issues that need to be addressed as part of developing a monitoring program to evaluate diazinon dormant spray stormwater runoff BMP efficacy. A summary discussion of these issues is presented below.

Clearly Define the Objectives of the Monitoring Program

There have been a number of reviews that provide guidance on how water quality monitoring programs should be developed/evaluated. These include the NRC (1990), Managing Troubled Waters, and the Lee and Jones-Lee (1992), “Guidance for Conducting Water Quality Studies.” The latter was originally developed by Lee and Jones in the 1970s as a US EPA report that was designed to develop guidance on monitoring toxic and other hazardous chemicals in the Great Lakes. In 1992, Lee and Jones-Lee updated this report and broadened the scope to include a wider variety of water bodies than just the Great Lakes. Excerpts from both of these reviews are appended to this report.

Both of these reviews indicate that one of the most important steps in developing a credible monitoring program to assess the ability of a particular practice or equipment to control one or more constituents to a desired degree is an explicit statement of the objectives of the monitoring program. Figure 1 presents a typical situation where there is need to determine the impact of stormwater runoff-associated diazinon on receiving water quality/beneficial uses. This figure depicts an orchard, which, during the dormant season (winter), will receive diazinon treatment. Following the application of diazinon, rainfall events will transport some of the diazinon to a nearby watercourse. In establishing a monitoring program for this situation, there is need to address a number of issues related to defining the objectives of the monitoring program. These include:

- How much (mass per storm) diazinon is transported from the area where applied?
Figure 1
Typical Diazinon Runoff Monitoring Situation

- What are the regulatory requirements for diazinon control and are these exceeded?
  - Does the concentration of diazinon exceed a water quality standard at a particular location/compliance point? At any location?
  - What is the allowed frequency of exceedance/violation?
  - What are the consequences/penalties for excessive exceedances/violations?
- What is the potential toxicity (diazinon concentration - duration of exposure) to:
  - Water column organisms?
  - Benthic organisms?
  - What is the area, distance and duration of potential toxicity?
- What is the measured toxicity in the runoff/discharge event at various locations in the discharge plume?
  - What is the maximum magnitude and duration of exposure and areal extent to measure toxic conditions?
- What is the impact of diazinon discharge to the beneficial uses of receiving waters?
- What impacts are there on the numbers, types and characteristics of receiving water aquatic life?
  - Is this significantly detrimental to the beneficial uses of the waterbody with particular reference to higher trophic organisms?
    - Water fleas vs large mouth bass
- What factors influence the water quality impacts of the diazinon runoff/discharge, such as rainfall intensity, duration, frequency; sprayed area characteristics, etc.?
  - Particular concern for high intensity, large storms
  - Will the monitoring program adequately characterize these factors?
- How well do the BMPs being investigated mitigate the impacts of the diazinon runoff for each of the water quality monitoring objectives?
  - What are the factors that influence the performance of the BMP?
    - Are these being adequately evaluated in the study program?
  - How many storms during a year and how many years must a BMP be evaluated to reliably conclude that it is an effective mitigation measure under the range of climatological and other factors that influence its performance?
- Others?

Each of the above water quality monitoring objectives has specific monitoring requirements. The OP Focus Group must clearly define the objectives for the monitoring program. Issues that need to be considered include:

- What objective(s) is to be achieved in each of the proposed projects (319(h), CALFED and Prop. 13)? – How reliably is the objective to be assessed?
- What is the level of funding needed to achieve the desired objective?
- Is there adequate funding to achieve the desired objective?

**Monitoring of Diazinon Use**

- Is diazinon use monitoring a reliable indicator of potential water quality impacts of diazinon runoff from areas where it is applied?
  - Does reduced diazinon use result in improved water quality?
    - If other pesticides are used as replacements for diazinon, what is their impact on water quality?
  - Are there adequate funds and methodology to properly evaluate the potential water quality impacts of alternative pesticides?

Those responsible for developing a stormwater runoff diazinon BMP management program in accord with the control Strategy need to carefully evaluate each of the above-listed issues as well as any others that are pertinent to their particular situation to clearly define the overall objectives of the monitoring program. Once these are defined, it is then possible to begin to formulate the monitoring program to achieve the desired objectives.

Typically water quality BMP evaluation focus on a comparison of the load of diazinon exported from particular land areas that are untreated, versus BMP treated. However, such a
comparison may not be appropriate in evaluating water quality impacts of the diazinon discharges. An issue that needs to be resolved is whether the monitoring is only going to address exceedences of the water quality goals, or whether the monitoring program is to be a comprehensive program that evaluates the water quality/ecological impacts of the diazinon-caused aquatic life toxic pulses associated with stormwater runoff events following diazinon application to an orchard. Both types of monitoring programs require a comparison between the BMP-treated runoff and untreated runoff.

**Accounting for Variability**

Since the measurements of diazinon concentrations at any particular time and location have a certain amount of variability associated with them, every monitoring program should evaluate the magnitude of the variability about any particular measurement, as well as for measurements made of different systems or at different times. This then introduces the need to evaluate the variability for each system monitored, and then establish, as part of the monitoring program goals, the amount and type of monitoring that is needed to achieve a certain prescribed degree of assessment of the difference between the two conditions (treated versus untreated) being evaluated. These issues should involve standard statistical techniques, where, *a priori*, a degree of reliability in assessing the difference between the treated and untreated systems is established.

For example, if it is desired to determine whether the BMP significantly affects the total amounts of diazinon exported from a particular plot of land during a stormwater runoff event to a 95-percent degree of confidence, then it becomes necessary to monitor a sufficient number of stormwater runoff events for both the untreated and BMP-treated runoff from particular areas to account for the inherent variability associated with such runoff and monitoring. Since the storm-to-storm variability in runoff of chemical constituents from a particular area is high, normally a large number of storms will need to be monitored, for both the untreated and BMP-treated systems, to reliably assess whether the BMP is effective in controlling the transport of diazinon from a particular area to the desired degree. Accounting for this variability has to be built into the monitoring program, or else the results of the monitoring program could readily prove to be inconclusive because a sufficient number of studies have not been conducted to reliably detect a change in diazinon export or impacts as a function of BMP implementation.

One of the issues that needs to be addressed is the number of samples that need to be taken during runoff events to adequately describe the maximum concentration in the runoff, as well as the worst-case load and overall load from the stormwater runoff event. The worst-case diazinon load relates to the load conditions that lead to the greatest concentration of diazinon in the receiving waters. The worst-case load will be highly dependent on precipitation intensity and duration during a rainfall event. There will be times during a rainfall runoff event when the concentrations in the receiving waters (and, therefore, their potential to cause toxicity) will be the greatest. This may not be related to any significant extent to the overall load transported from the evaluation area for a particular storm. One of the issues that needs to be considered as part of any evaluation of the efficacy of BMPs is the relationship between the worst-case load of diazinon and overall load.
It is important to remember that the purpose of the BMP is to control aquatic life toxicity in the receiving waters. As shown in Figure 2, toxicity/impact has a concentration/duration of exposure component that must be considered in evaluating the ability of a BMP to properly control diazinon-caused aquatic life toxicity in the receiving waters for the runoff.

**Figure 2: Concentrations of Toxicant, Duration of Exposure Impact Relationship**

ISSUES:
- What Is Impact of Toxicant on Numbers, Types & Characteristics of Desirable Aquatic Life?
  - Direct & Higher-Trophic-Level Impacts
  - Impacts on Zooplankton That Are Essential, Non-Replaceable Food for Larval Fish
  - Consider both Acute & Chronic Impacts
- Does This Impact Represent a Significant, Adverse Impact on Beneficial Uses of Waterbody Fisheries & Other Aquatic & Terrestrial Life of Importance to the Public?

Some individuals in the stormwater runoff water quality management field use what is called an “event mean concentration” to estimate total loads of chemical constituents. While it is appropriate for estimating total loads, it is not appropriate to evaluate water quality impacts of the loads, since it is not the average concentration over a runoff event that determines toxicity. For those monitoring programs where there is interest in evaluating the water quality impacts of those loads, a critical evaluation needs to be made as to the concentration/duration of exposure during the relationship in the receiving waters which would have the greatest impact on their beneficial uses.
It should be recognized that the efficacy of BMPs of the type that are typically being considered for managing diazinon runoff from dormant-sprayed orchards is likely dependent on the magnitude of the stormwater runoff event, where BMPs such as grassy strips, detention basins, etc., may be somewhat effective at low flow and for small storms, but are not likely to be effective at high flow. It is the high-flow situations which are of greatest concern, since this would likely result in the greatest transport of any diazinon applied for dormant spray from the sprayed area to nearby surface waters. This situation typically applies to near-field (the point of discharge). However, in far-field situations, higher flows may actually dilute the diazinon concentrations if the higher flow is largely derived from non-diazinon sprayed areas. The monitoring program needs to be able to evaluate these situations for both near-field and far-field impact information as a function of rainfall runoff intensity and duration.

The overall approach that is being developed in the OP focus group for diazinon control BMP evaluation is to select areas where particular types of BMPs to control diazinon runoff can be implemented, and the impact of the BMPs can be reliably monitored. While, at this time, the focal point of the CVRWQCB’s orchard spray diazinon control program is on the mainstem of the Feather and Sacramento Rivers, it is suggested that the primary monitoring that will need to be done would be on smaller tributaries to the mainstems. By examining the worst case situation near the point where the runoff from the sprayed orchard occurs, it should be possible to discern potential impacts in tributary streams and, thereby, through evaluations of fate-transport information that needs to be done as part of the monitoring to evaluate the potential impacts that would be expected to occur in the mainstem of the Sacramento or Feather River.

Adequate Funding

Once the objectives of the monitoring program are clearly defined and the general characteristics of the site to be evaluated are known, then an assessment has to be made as to the number, types, locations, frequency, etc., of sampling that is to be conducted to achieve the desired objectives. This is the first phase of establishing the budget for the monitoring program. It is important that this approach be followed and not the traditional approach of establishing a budget and then developing a monitoring program to fit the budget. That approach is a primary cause of the failure of most water quality monitoring programs to provide definitive information on the water quality characteristics of the system being monitored. So long as program administrators are led to believe that the ad hoc monitoring program, which is budget-driven, provides reliable information, water quality monitoring programs will continue to largely be a waste of the funds spent on them. Programs of this type are largely chemical constituent monitoring that provide limited information on water quality/beneficial uses impairment. Those responsible for developing true water quality programs should work with the program administrators in defining the monitoring program goals and then, most importantly, informing the program administrators what it will cost to achieve those goals with an adequate degree of reliability.

If insufficient funds are available to achieve the goals with a desired degree of reliability, then rather than cutting back on the monitoring program to match the funds available while maintaining the original program goals, the monitoring program goals should be redefined to
match the funds available considering the variability of the system being monitored. This approach leads to an iterative monitoring program development where the monitoring program goals and the funding available are properly matched.

**Model Monitoring Program**

This section presents an example of a monitoring program for a situation where a particular orchard area is being used as a demonstration area for evaluation of a particular BMP to control diazinon applied as a dormant spray in stormwater runoff that leads to aquatic life toxicity in the receiving waters for the runoff from the orchard.

**Develop an Understanding of the Hydrology of the Area and Potential Upstream Contributions of OP Pesticides during Stormwater Runoff Events.** The first step in developing a monitoring program to evaluate the efficacy of a particular BMP or group of BMPs to control the runoff of diazinon from an area where it is applied is to develop an understanding of the hydrology (i.e., water movement) under stormwater runoff and irrigation releases/discharges. All points where runoff from the test area can discharge to a particular receiving water should be identified. If possible, the receiving water stream should be gaged just upstream of the test area and either at the point of runoff from the orchard or just downstream of this point. An estimate should be made of the expected amount of runoff that will occur from the fields under various antecedent moisture conditions, rainfall intensity and duration.

A recording rain gage should be installed in the area where the BMP is being conducted.

A survey of upstream land use should be conducted to be certain that there are no major expected contributors of diazinon in stormwater runoff or wastewater discharges.

The location selected should be one where the runoff from the test area would be expected to contribute to or cause *Ceriodaphnia* toxicity in the receiving waters for the runoff.

At least one – and preferably three – years of pre-BMP implementation data should be collected from the test area in order to gain insight into the amounts of diazinon export that occurs from the test area under various climatological and other factors that influence diazinon export.

While the focus of this BMP evaluation program is on stormwater runoff from diazinon-sprayed orchard areas, it will be important to also assess the aerial drift that occurs associated with spraying of the orchard. A pre-BMP implementation monitoring program for aerial drift under normal operations and associated with the evaluation of the BMPs should be conducted through the use of rainfall and dry fallout collectors. These collectors should be positioned around the orchard area at various distances.

The orchard that is evaluated should preferably be located upstream of other orchards that may be contributing diazinon to downstream tributaries to the mainstem of the Sacramento or Feather River. It may be necessary to evaluate aerial drift from sprayed areas from various types of methods of application of diazinon, since the amount of drift is likely to be a function of
application methodology.

Several years of pre-BMP implementation monitoring of the aquatic biota in the water column and sediments upstream, near the point of discharge of the orchard runoff, and downstream of this location should be conducted immediately prior to, during, and just after the dormant spray season. At least two upstream stations and two downstream stations should be used. The physical habitat characteristics of each station should be similar, in terms of water depth, velocity, bottom substrate characteristics, etc.

One of the major problems with trying to evaluate the efficacy of a particular BMP to reduce the impact of the use of diazinon as a dormant spray on receiving water beneficial uses is the essentially unknown coupling that exists between the presence of diazinon in a stream and its impact on the beneficial uses of the waterbody. For the purposes of TMDL implementation and evaluation in this program, it is assumed that the assessment of aquatic life toxicity, together with measurements of diazinon concentrations, is a reliable surrogate for beneficial use assessment. To help in this regard, this monitoring program should include some focused bioassessment studies. Transport studies should be conducted to measure the concentrations and flows of the runoff and the upstream/downstream waterbody receiving the runoff. It is suggested that samples taken every two to four hours prior to and during runoff events be collected.

(\textit{this section will be expanded once more information is available on the characteristics of the BMP study areas and an agreement is reached on the objectives of the monitoring program and the funding to carry out this program is available for review.})

**Importance of Aquatic Chemistry in BMP Efficacy and Water Quality Impact Evaluation.** The purpose of the water quality BMPs that will be developed is the control of the concentration/impacts of OP pesticides. The development of technically valid, cost effective BMPs as well as a reliable assessment of OP pesticide stormwater runoff water quality impacts requires the proper incorporation of aquatic chemistry into the evaluations. Contrary to the simplistic approach that is often used by those who are not familiar with aquatic chemistry, it is not a list of the chemical concentrations found in a water sample. Such a list is a presentation of chemical characteristics, not chemistry.

Chemistry involves the study of the transport and reactions of the chemical constituents of concern. It is devoted to assessing the advective transport, mixing, diffusion and dispersion, as well as the chemical kinetics and thermodynamics of the chemical reactions that govern the chemical species of concern in a particular situation. Figure 3 presents the aquatic chemistry wheel that was developed by Drs. Lee and Jones-Lee. For each chemical, such as a heavy metal with multiple oxidation states, there are a variety of chemical reactions, represented by the spokes in the wheel, that lead to products at the rim. It is the products at the rim that determine whether a particular chemical will be effectively removed by a particular BMP as well as the impact of the untreated as well as the treated stormwater runoff on the beneficial uses of the receiving waters for the runoff/discharges.
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
Through proper application of aquatic chemistry, considerable insight can be gained on the expected performance of BMPs under various runoff conditions. For example, the properties of diazinon are such that it has low tendency to sorb (attach) onto surfaces. This means that BMPs that are based on sorption for removal will not be effective unless very large sorption areas are provided and extended periods of time are available for sorption to take place. It is for this reason that retention basins, vegetative strips and related BMPs including setback areas, will not be effective in controlling diazinon runoff from treated areas, especially under high flow conditions.

**Evaluation of Beneficial Use Impact**

The evaluation of the potential significance of toxicity associated with stormwater runoff events or discharges from municipal or rural sources requires a comprehensive field study that reliably evaluates the hydrology and hydraulics of the discharge/runoff situation as it mixes with the receiving waters and the concentrations of chemicals, both conservative (non-reactive) and reactive chemicals that are potentially toxic to aquatic life in the receiving waters for the discharge/runoff. There are basically three focal points for any impact evaluation: the sediment-associated organisms (associated with a particular area of the waterbody’s sediments), the planktonic organisms (moving with the water, with only limited locomotion ability) and the nectonic organisms (free-swimming). For the sediment-associated organisms, consideration must be given to the epibenthic organism impacts as well as those that are present within the sediments.

For each type of organism, there is need to assess the duration of exposure and the integrated magnitude of exposure to the toxicant(s). This assessment frequently requires considerable understanding of the movement of water and the associated constituents that are of concern. While generally for planktonic organisms and dissolved constituents, it is fairly straightforward (with appropriate sampling) to determine the exposure situation, for constituents associated with particulates where the particulate-bound fraction is toxic, the issue of the movement of the particulates also has to be evaluated. This is typically a much more complex issue than for dissolved constituents.

The current overall regulatory requirements for controlling aquatic life toxicity due to pesticides and other potentially toxic constituents is to protect the water quality - designated beneficial uses of the waterbody. As it relates to aquatic life resources, this is typically understood to mean the numbers, types and characteristics of desirable forms of aquatic life in the potentially impacted waterbody. While, for many situations where the toxicant is toxic to a variety of types of aquatic life at low concentrations such as some heavy metals to zooplankton, fish larvae, etc., there is a fairly well defined relationship between measured toxicity and impacts on a number of forms of aquatic life in the receiving waters. However, for the organophosphate pesticides such as diazinon and chlorpyrifos where the toxicity is only manifested to a limited number of types of zooplankton and benthic organisms, there are important questions regarding how to translate the laboratory measured toxic pulses of diazinon associated with stormwater runoff from recently treated areas to adverse impacts on the designated beneficial uses of the receiving waters. This situation may justify conducting field studies to determine whether the
toxic pulses of diazinon in stormwater runoff from dormant sprayed orchards are significantly adverse to higher trophic level organisms such as fish larvae.

It is important to note that finding aquatic life toxicity in a standard toxicity test of the types that are used does not necessarily mean that this toxicity is significantly adverse to either the ecosystem or the water quality-related beneficial uses. It does mean, however, that there is a potential for ecological and/or water quality impacts due to the laboratory measured toxicity that needs to be evaluated. In the current regulatory framework, however, where the US EPA interprets a congressional mandate for protection of the nation’s water quality/beneficial uses, any toxicity found under standardized conditions must be regulated as though the toxicity were significantly adverse to the aquatic life-related beneficial uses of the waterbody, either directly to higher trophic level organisms, or through the food web, as well as adverse to the ecosystem’s functioning. This “worst-case” approach is in accord with the US EPA’s approach for implementing the 1972 amendments to the federal water pollution control regulations (“Clean Water Act”). In general, in many respects, the Clean Water Act is implemented in such a way so that if there is a significant question about a potential water quality impact, it is assumed that the impact will occur unless it is demonstrated otherwise. The US EPA has made it clear that those interested in continuing to use/discharge chemicals to the nation’s waters have the opportunity to use good science to demonstrate that a discharge may take place, including toxic discharges, provided it is shown that these discharges are not adverse to beneficial uses, which includes protection of ecosystem functioning.

In those situations where potentially significant aquatic life toxicity is found to zooplankton, there is need to evaluate the potential water quality/ecological significance of this toxicity. A distinction should be made between ecological significance of the toxicity – as it may impact the function of the ecosystem that exists or could exist in the waters under consideration – and the water quality significance of the toxicity – as it may impact the designated beneficial uses of the waterbody of concern.

With respect to ecological significance, it is well understood that there can be appreciable toxicity to certain forms of aquatic life which can eliminate a species or so without adversely impacting the ecosystem’s functioning. Similarly, from a water quality/beneficial use impact assessment situation, there can be toxicity to certain forms of aquatic life, especially lower trophic level forms, without impairing the beneficial uses of the waterbody from the public’s perspective. For example, in many situations, toxicity to algae would not be considered significantly adverse to the beneficial uses of a waterbody if the algae are already present there at concentrations which are impairing the beneficial uses. Further, toxicity to mosquito larvae without toxicity to essential larvae gamefish food could be considered beneficial. Similarly, toxicity to rough fish populations, such as carp, may be considered acceptable if it did not also affect certain gamefish species, such as trout or bass. The issue, therefore, in evaluating the impact of toxicity on a waterbody’s ecosystem or its water quality/beneficial uses, is one of understanding the range of organism types and magnitude of toxicity and its persistence that occurs in association with a particular situation.
The elimination of all toxicity in the State’s waters due to diazinon runoff from dormant sprayed orchards will almost certainly mean that diazinon cannot be used as a dormant spray. This situation arises from the fact that the properties of diazinon are such that the likelihood of developing an affordable BMP that will control diazinon runoff from dormant sprayed orchards under major rainfall runoff events is very small, to essentially zero, and since diazinon’s use in some instances is cost-effective in controlling certain types of orchard insects and since alternative pesticides to diazinon may be at least, if not more adverse to the beneficial use of waterbodies, consideration should be given to conducting the studies necessary to determine whether the laboratory-based *Ceriodaphnia* toxicity, represents a significant adverse impact on desirable higher trophic forms of aquatic life such as game fish larvae, endangered species, etc.

Lee and Taylor (1999), and Lee et al. (2000 and 2001ab) conducted a fate/persistence study for OP pesticide-caused toxicity for stormwater runoff events in 1998-2000 into Upper Newport Bay in Orange County, California. This study involved monitoring San Diego Creek as it enters Upper Newport Bay, which is the primary tributary of the Bay, during a stormwater runoff event. Upper Newport Bay is a marine bay with typical salinities on the order of 30 ppt. Stormwater inputs to the Bay generally occur as a freshwater lens floating on the marine waters of the Bay. The Bay has a three- to four-foot tide and about a ten-day tidally controlled hydraulic residence time. The freshwater input from San Diego Creek mixes to a limited extent with the Bay waters to form the freshwater lens with a salinity greater than that of freshwater, but considerably less than that of the Bay waters. Based on the total TUa for *Mysidopsis* toxicity of about 10, anytime the salinity of the Bay waters during a runoff event is greater than about 3 ppt, the waters would be expected to be nontoxic to *Mysidopsis*, since insufficient toxic freshwater has mixed into the Bay waters to create toxic exposure conditions.

The Bay monitoring program consisted of evaluating the net advective down-Bay transport of the freshwaters in the Bay to assess the average downstream velocity. At about 6- to 10-hour intervals, samples of Bay waters near the surface, near mid-depth and near the bottom were taken. Temperature, salinity, OP pesticides and, for some samples, *Mysidopsis* toxicity were measured. Based on the results of this testing, it was found that the chlorpyrifos-caused toxicity persisted for about a day after the stormwater runoff event had ceased. There was measured and a potential for toxicity near the mouth of where San Diego Creek entered the Bay in the freshwater lens. These studies, therefore, concluded that, in order for toxicity to be significant to the Bay ecosystem and to the Bay’s water quality/aquatic life-related beneficial uses, it would be necessary for a marine zooplankter that normally lives in 30 ppt marine waters to migrate into the freshwater lens near the mouth of the Bay and to receive a toxic exposure during about a one-day time.

Note that the freshwater zooplankters that come into the Bay from San Diego Creek watershed are killed in the Bay by the salinity, so the OP pesticide-caused toxicity to them is not an issue in the freshwater part of the bay because of the salinity-controlled toxicity. In order for the chlorpyrifos caused toxic pulses to be significantly adverse to the beneficial uses of the bay, not only must the marine zooplankter receive a toxic exposure, these zooplankter(s) must be of critical ecological importance to the Bay’s ecosystem and/or be of significance to higher trophic
level marine aquatic life that inhabits the Bay, such as being an essential, non-replaceable food source for desirable forms of fish or other higher trophic level aquatic life. Lee and Taylor, through the use of modeling of the Bay’s characteristics under various magnitude stormwater runoff events, concluded that there would be several storms per year where there was a potential for toxicity due to chlorpyrifos to *Mysidopsis*.

Lee and Taylor (1999) and Lee et. al., (2000-2001ab) concluded that, while these conditions could occur, the likelihood of their occurring is small and, therefore, under the conditions of OP pesticide-caused aquatic life toxicity entering Upper Newport Bay, it is unlikely that the stormwater runoff-associated toxicity causes significant impairment to the beneficial uses of the Bay or its ecosystem.

It should be noted that toxicity that occurred under laboratory conditions after several days of exposure would not be of concern in Upper Newport Bay, since the potential for aquatic organisms to receive that type of exposure in a rainfall runoff event is remote due to the tidal mixing of Bay waters with the freshwater input.

Intensive fate/persistence studies of the type conducted by Lee and Taylor are difficult to carry out and expensive, but they are necessary to evaluate whether toxicity measured under laboratory conditions is likely to occur in the field to a sufficient extent to be adverse to aquatic life.

While the studies were conducted under the conditions that exist in Upper Newport Bay, similar situations occur in stormwater runoff to San Francisco Bay, where it is unlikely that the OP pesticide-caused aquatic life toxicity in stormwater runoff to San Francisco Bay from urban areas is significantly adverse to the beneficial uses of the Bay.

Lee and Taylor (1999) and Lee et. al., (2000) have pointed out that the laboratory measured toxicity of diazinon and chlorpyrifos that occurs in the freshwater tributaries of Upper Newport Bay is not a reliable assessment of a potential water quality impact of these pesticides to aquatic life in the Upper Newport Bay tributary streams. These streams are non toxic between stormwater runoff events. The maximum travel time for zooplankters during a stormwater runoff event between the headwaters of the stream and when they enter Upper Newport Bay is about eight hours. Therefore, laboratory toxicity that is not manifested until a day or two after the initiation of the test is not a proper measure of toxicity to zooplankton in the Upper Newport Bay tributary streams. These zooplankton may experience no toxicity due to the OP pesticides prior to the time that they are killed by the salinity in the bay. There may, however, be toxicity to benthic organisms in the tributary streams due to the toxic pulses associated with stormwater runoff that needs to be assessed as to whether this toxicity is adverse to the beneficial uses of these streams. While these streams are classified as having aquatic life beneficial uses, they are basically concrete lined channels whose primary function is to transport stormwater to prevent flooding.
The situation in the city of Sacramento, where studies have shown that Arcade Creek, which drains predominantly residential areas, has sufficient diazinon to be toxic to *Ceriodaphnia* over extended exposures, is of concern with respect to potential impacts on the aquatic life resources of Arcade Creek. Since, in general, urban aquatic life toxicity is associated with stormwater runoff events, the fact that there is a potential for aquatic life toxicity in Arcade Creek, even under dry weather flow conditions, requires that studies be conducted of the dry weather flow to determine the sources of the diazinon that are present under those conditions. According to Denton (pers. comm., 2001), the elevated concentrations of diazinon under dry weather flow are found throughout Arcade Creek and seem to originate in its headwaters. Forensic studies of the headwaters should be conducted to determine the origin of the diazinon under dry weather flow.

Studies on the fate of the Arcade Creek toxicity within the Sacramento River have shown that this toxicity does not persist in the river due to its rapid dilution in the river water. Therefore, the water quality significance of the Arcade Creek toxicity issue needs to be evaluated in terms of whether this toxicity is significantly adverse to the beneficial uses of the creek and most importantly, how would the beneficial uses of the creek improve, if any, if the diazinon and chlorpyrifos caused toxicity were eliminated.

Lee and Jones-Lee (2001) have recently completed a report presenting the results of the aquatic life toxicity that occurs in the City of Stockton sloughs. Stockton has a number of freshwater tidal sloughs which are drainage ways for urban stormwater and for some of them, upstream agricultural areas’ watershed waters. Studies by the Central Valley Regional Water Quality Control Board and the DeltaKeeper conducted between 1994 and 1999, as presented by Lee and Jones-Lee (2001) have shown that the Stockton slough water becomes highly toxic to *Ceriodaphnia* in each rainfall event. They are generally non-toxic between events. The toxicity has been found to be primarily due to diazinon with occasionally chlorpyrifos contributing to it. The Stockton sloughs are connected to the Delta and could be important nursery areas for Delta aquatic life. An issue that needs to be evaluated is whether the diazinon caused aquatic life toxicity that persists for a day or so in the slough waters and for some undefined likely limited distance into the Delta is significantly adverse to the beneficial uses of the sloughs and Delta waters. Lee and Jones-Lee (2001) point out that an even more important issue is that since the use of diazinon in urban areas is being phased out over the next three years, studies need to be initiated on the water quality impacts of the replacement pesticides that will be used in Stockton on the sloughs and the Delta.

There are situations, however, associated with former (and possibly still, at times) use of diazinon as a dormant spray in orchards in the Sacramento River system. Kuivila and Foe (ref) followed a pulse of diazinon-caused *Ceriodaphnia* toxicity for over a week from the Sacramento/Feather River down through the Delta. It appears, based on recent monitoring of the Sacramento and Feather Rivers just downstream of where diazinon is used as an orchard dormant spray, that the magnitude of the toxicity caused by this use is much less than it was a few years ago. Situations where high levels of aquatic life toxicity persist over considerable areas for a
week or more are conditions that deserve a high level of attention because of the potential for adverse impacts to both the ecosystem functioning and water quality/beneficial uses.

As discussed by Lee et al. (2001ab), it is important in evaluating the potential impacts of aquatic life toxicity, such as caused by the OP pesticides, to determine the potential improvement in ecosystem function/water quality beneficial uses associated with controlling the toxicity. As part of evaluating the water quality benefits of controlling diazinon, or for that matter, other pesticide caused aquatic life toxicity in urban streams, the improvement in the urban streams’ beneficial uses should be evaluated, considering the fact that most urban streams have been channelized to such an extent as part of flood control efforts so that the aquatic life habitat in the stream is severely degraded. The appropriateness of controlling aquatic life toxicity due to residential use of pesticides for some urban streams needs to evaluate how the elimination of toxicity will improve, if at all, the designated beneficial uses of the stream and the receiving waters of the stream’s discharge.

It is important to understand that the issue is not one of controlling toxicity caused by one pesticide without potentially substituting another pesticide which could be even more toxic to a greater group of organisms than the OP pesticide. Pesticides are going to be used. The current US EPA Office of Pesticide Programs and the California Department of Pesticide Regulation’s approach for registering pesticides does not evaluate whether the use of a registered pesticide in accord with the registration label can lead to aquatic life toxicity in the receiving waters for stormwater runoff from the area where the pesticide is applied. So long as these conditions prevail, where one pesticide can be substituted for another, and thereby cause even greater aquatic life resource damage than the one that caused the original concern, there is need to carefully develop the regulatory approach which would eliminate the use of an effective pesticide as a pest control agent only to substitute another pesticide without proper evaluation for pest control.

An important aspect of toxicity impact assessment is the need to continue to focus on toxicity measurements as opposed to chemical measurements as a surrogate for toxicity. This is especially true today, where there is substantial substitution of other pesticides, such as pyrethroid pesticides for the OP pesticides in urban and in rural areas. A false sense of security can be obtained through seeing decreases in diazinon concentrations that is equated, without toxicity tests, to a decrease in impacts caused by diazinon, when in fact the impacts due to the other pesticides that are substituted for diazinon may become greater than what they were when diazinon was used.

The evaluation of the water quality/ ecological significance of the diazinon-caused toxic pulses associated with its use as a dormant spray should be funded by those who wish to continue to use and sell this pesticide. At this time, there are reasonable questions about whether the toxicity found in stormwater runoff from dormant sprayed orchards is significantly adverse to the beneficial uses of the Sacramento and Feather Rivers. The current regulatory requirements, however, which mandate that this toxicity be controlled could be relaxed to properly reflect its impacts on the beneficial uses of these waters should it be found that they do not significantly
impact higher trophic organisms. Without the needed studies, there can be little doubt that the ability to use diazinon as an orchard dormant spray will ultimately be curtailed in order to satisfy current “worst-case” Clean Water Act regulatory requirements.

**Impact of BMPs on Ag Sources of Other Constituents of Concern**

While the focus of the OP Pesticide Focus Group is developing BMPs to control diazinon runoff from dormant sprayed orchards, the ag community in the Sacramento and Feather River watersheds as well as elsewhere in the Central Valley will eventually need to evaluate many of the same BMPs being considered for control of diazinon runoff with respect to how they impact the runoff of other constituents of concern. Setback from application-buffer strips, vegetative strips, retention basins, etc., will be need to be evaluated as BMPs for control of other constituents in order to comply with future regulatory requirements. It is appropriate as part of determining the ability of certain BMPs to control diazinon runoff from dormant sprayed orchards that measurements be made of how these same BMPs impact the runoff of other constituents of concern from these same areas. A brief discussion of potential constituents of concern for which the ag community in some parts of the Sacramento and San Joaquin River watersheds will need to develop BMPs to control the concentrations discharged from ag lands is presented below.

**Organochlorine Pesticides.** Many of the waterbodies in the Sacramento and San Joaquin River watersheds contain fish with sufficient concentrations of organochlorine pesticides (OCls) such as DDT, chlordane, dieldrin, etc., so that they are a threat to cause cancer in those who use the fish as food. This situation has caused the CVRWQCB to list 11 waterbodies in the Sacramento River, San Joaquin River watersheds and the Delta as 303(d) “impaired” waterbodies due to excessive bioaccumulation of OCls in edible fish tissue. It is also known that there are other waterbodies, such as the mainstem of the Sacramento River, that will need to be listed in the next 303(d) listing because of excessive concentrations of the organochlorine pesticides and PCBs in edible fish tissue.

The existing listing has caused the CVRWQCB to develop a TMDL to control the input of organochlorine pesticides from agricultural and other areas where these pesticides were used previously. Even though these pesticides have not been used for many years, they are still present in some agricultural soils and runoff from ag areas at concentrations which are a threat to lead to excessive OCl bioaccumulation in fish. Studies are being planned to determine some of the areas in the Sacramento and San Joaquin River watersheds where organochlorine pesticides are still being transported from ag areas at sufficient concentrations to cause or contribute to their excessive bioaccumulation in edible fish. There will likely be need in the ag community in some areas to control the runoff/discharge of organochlorine pesticides to reduce their input to waterbodies where excessive fish bioaccumulation is occurring. Some of the same BMPs that will be used for organophosphate pesticides will likely be considered as candidate BMPs for organochlorine pesticides. Therefore, it would be appropriate to evaluate whether there are concentrations of organochlorine pesticides present in stormwater runoff and irrigation water releases at concentrations above US EPA/State of California Toxics Rule (CTR)
If concentrations of CTR criteria/objectives are found, then an evaluation should be made as to how the BMPs being evaluated impact their runoff from the orchard area.

In addition to the legacy organochlorine pesticides, such as DDT, being of concern as a cause of water quality impairment associated with stormwater runoff and irrigation water discharges from ag areas where they were used, lead arsenate was widely used as a pesticide in some areas. This use has left potentially significant residues of lead and arsenic in soils. Part of the residues present in the soil would be expected to be present in stormwater runoff and irrigation water discharges from the areas of former use. As with the organochlorine legacy pesticides, concentrations of lead and arsenic in stormwater runoff from ag and other areas should be measured in OP pesticide BMP evaluation to be certain that the runoff concentrations do not exceed CTR criteria in the runoff waters as well as the new arsenic drinking water MCL that is being promulgated by the US EPA.

Other Pesticides and Ag Chemicals. There are a wide variety of pesticides and agricultural chemicals that are present in stormwater runoff irrigation water releases that have not been adequately evaluated with respect to their presence above water quality criteria/objectives in the Central Valley. For example, Kuivila (2000) has reported that there are over 150 pesticides used in the Central Valley which are a potential threat to cause aquatic life toxicity in stormwater runoff/ag discharge waters. In addition to currently used pesticides, some ag areas are being treated with heavy metals such as copper and zinc which will be present in stormwater runoff irrigation water releases from areas of treatment. At this time, there is limited information as to whether the treatment of ag lands with heavy metals results in violations of water quality criteria/standards in the receiving waters for stormwater runoff irrigation water releases from the treated areas. Few of these currently used pesticides/ag chemicals have been evaluated with respect to their potential to cause impairment to the beneficial uses of the receiving waters for stormwater runoff irrigation water releases. In order to address this issue, Jones-Lee and Lee (2000) have developed a “proactive” approach for identifying the potential water quality impacts of the alternative pesticides that are used as replacements for the OP pesticides as well as the other pesticides and other ag chemicals that are in use today that have not been properly evaluated with respect to water quality impacts in the receiving waters for the stormwater runoff irrigation water releases.

With the phased down use of OP pesticides, increasing use of other pesticides will occur, some of which are as toxic or more toxic to aquatic life than the OP pesticides. As ever increasing regulatory constraints are developed and imposed, there will be need to evaluate BMPs to control alternative to the OP pesticides runoff/discharges from ag areas in those instances where the concentrations in the runoff/discharges represent a threat to receiving water beneficial uses. It will be important, as part of developing BMPs to control OP pesticide runoff to evaluate the potential water quality impacts of substitute pesticides that are used as replacements for the OP pesticides and the ability of conventional BMPs to control their runoff.

Unknown Caused Toxicity. The Central Valley Regional Water Quality Control Board and CALFED have listed the control of unknown caused aquatic life toxicity as a high priority area.
Major research efforts are being developed to begin to determine the locations where unknown caused aquatic life toxicity is being found in the Central Valley. These studies will include attempts to identify the chemicals responsible for the unknown caused toxicity. Even without identifying the specific chemicals responsible, through forensic studies utilizing selective toxicity tests in a waterbody’s watershed, it will be possible to identify sources of unknown caused toxicity which in turn will need to control this toxicity by those responsible for managing the lands from which it is being derived. OP pesticide BMP evaluations should include measurement of the total aquatic life toxicity present in the runoff waters and how much of the total toxicity can be attributed to known causes such as diazinon and chlorpyrifos. This will require the use of dilution series toxicity testing with and without PBO. This approach has been proven to be highly effective in identifying the presence of unknown caused toxicity in the Upper Newport Bay watershed (Lee and Taylor 1999 and Lee et. al., 2001ab).

**Sediment Toxicity.** Increasing attention is being given to regulating the toxicity of aquatic sediments. The US EPA is developing sediment quality guidelines that can be used for this purpose. Within a few years, dischargers of constituents that become toxic in sediments could become responsible for controlling the input of these constituents from land runoff/irrigation water discharges. Examples of constituents that can cause sediment toxicity include aquatic plant nutrients that develop into algae or other aquatic plants which die and become part of the sediments, organic nitrogen present in the plant materials as well as particulate nitrogen discharged in land runoff that accumulates in sediments and, through sediment mineralization processes, produces ammonia which causes sediments to be toxic.

**Aquatic Plant Nutrients (N and P compounds).** Excessive fertilization leading to excessive growths of algae and other aquatic plants which impairs the beneficial uses of waterbodies is a common, significant problem in the Central Valley. The US EPA is aggressively pursuing the development of numeric chemical specific nutrient criteria that will cause the state and the regional boards to adopt numeric chemical specific water quality objectives for nitrogen and phosphorus compounds as they may lead to excessive fertilization of waterbodies. This excessive fertilization can lead to significant impairment of the use of the waters for domestic water supply purposes, such as causing taste and odors, and increased water treatment costs. It can also cause violations of water quality objectives for pH and DO through the diel photosynthetic/respiration cycle. Also, while it tends to stimulate increased growth of fish, this growth is typically manifested in less desirable fish such as carp. Further, excessive fertilization can significantly impair recreational use of waterbodies.

The Delta, San Joaquin River watershed and some parts of the Sacramento River watershed contain concentrations of nitrogen and phosphorus compounds that are in excess of the default ecoregion based nutrient criteria that the EPA is proposing for California. This can lead to waterbodies being listed as a 303(d) “impaired” waterbody because of excessive nutrient concentrations for which there will be need to develop a TMDL to control nutrient discharges in stormwater runoff in irrigation water releases from agricultural areas. Many of the same BMPs that are proposed for evaluation to control runoff/releases of OP pesticides will need to be evaluated with respect to their ability to control total phosphorus, soluble orthophosphate, nitrate,
nitrite, ammonia and organic nitrogen in stormwater runoff from orchard and other ag areas where nutrients are applied as a fertilizer. As part of evaluating the efficacy of the control of OP pesticides by BMPs, measurements should be made of the ability of these same BMPs to control aquatic plant nutrients in stormwater runoff and irrigation water releases.

**Total Organic Carbon.** The Delta provides a domestic water supply for about 22 million people in California. Water utilities that use Delta waters experience excessive concentrations of total organic carbon (TOC) compared to US EPA regulatory limits. This TOC is of concern because, through water disinfection, elevated concentrations of trihalomethanes (THMs) are formed which represent a human health risk to cause cancer in those who consume the water for domestic purposes. This situation will likely lead to the listing of the Delta and many of its tributaries as 303(d) “impaired” waterbodies because of excessive TOC. TMDLs will need to be developed to control the excessive TOC which will include controlling TOC export from ag and urban areas in stormwater runoff and irrigation water releases. As with the other constituents of concern, discussed herein, an evaluation of the presence of TOC in the orchard stormwater runoff irrigation release waters relative to the EPA regulatory requirements for domestic water supplies of 3 mg/L TOC, as well as an evaluation of how the BMPs that are being evaluated for OP pesticide control impact TOC export from agricultural lands should be conducted.

**Dioxin and Furans.** The dioxins and furans represent a group of organochlorine compounds that are formed during combustion and are present in highway and street stormwater runoff. Further, burning of plant materials has been found to produce dioxins and furans. They have also been found as contaminants in certain manufacturing processes and some ag chemicals. Some of the dioxins and furans have a high potential to cause cancer at low concentrations and are among some of the most hazardous chemicals known. Dioxins and furans tend to accumulate in fish to levels that are hazardous to those who use the fish as food. There is limited information on the concentrations of dioxins and furans in stormwater runoff and fish in the Central Valley. Studies in other areas have shown, however, that in areas such as the San Francisco Bay, that dioxins and furans do bioaccumulate to excessive levels in fish where there is need to control the input of dioxins and furans to waterbodies. Studies are being developed to assess the presence of dioxins and furans in Central Valley waters and fish. Within a few years, the magnitude of the dioxin and furan water quality problem in the Central Valley should be better understood. This could lead to the need to develop BMPs to control dioxins and furans from specific sources that could include ag lands where burning has been practiced.

**Mercury.** Fish taken from many areas of the Central Valley have been found to contain excessive concentrations of mercury in edible tissue. This mercury is a threat to cause neurological damage in fetuses and young children. While some areas of the Central Valley, especially areas where mercury and gold mining has occurred, are already on the 303(d) list of “impaired” waterbodies because of excessive bioaccumulation of mercury, there are other areas that will be added to the 303(d) list of “impaired” waterbodies due to excessive bioaccumulation of mercury in fish. It is likely that as further studies are done, many areas not now considered significant sources of mercury outside of former mining areas will need to investigate the need to develop BMPs to control mercury runoff from these areas. This could readily include
agricultural lands where there has been no history of mercury use, yet mercury is being found in stormwater runoff at concentrations which are a threat to bioaccumulate to excessive levels in fish. As with other constituents of concern, BMP development/evaluation for the OP pesticides should include measurements of mercury where, if the concentrations found are above about 2 ng/L, the ability of the OP pesticide BMPs to remove mercury should be evaluated.

**Sediment/Turbidity.** The CVRWQCB Basin Plan has strict limits on the amount of increased turbidity that can occur in waterbodies. While ag runoff/discharges is not yet regulated to control turbidity increases caused by stormwater runoff irrigation water releases, the imposition of the turbidity limits currently in the CVRWQCB Basin Plan to ag runoff would lead to major efforts to control erosion/turbidity in ag runoff. As part of OP pesticide water quality BMP evaluation, an assessment of the amount of turbidity present in the runoff and how the BMP influences this turbidity should be made.

**Selenium.** Currently the CVRWQCB has developed a TMDL to control selenium discharges to the San Joaquin River. It is possible that the current selenium discharge limit will be revised so that even more stringent control of selenium in ag runoff will be needed. All OP pesticide BMP evaluations should include determination of whether selenium is present in the stormwater runoff irrigation water discharges at concentrations that are near the current selenium water quality objective of 5 µg/L. For those situations where selenium is present in stormwater runoff irrigation water releases above a few µg/L, an evaluation should be made as to how the conventional BMPs being investigated for OP pesticide control impact selenium runoff from the area.

**Salt/TDS.** Total salts, measured as total dissolved solids (TDS), or electrical conductivity, are of concern to water utilities that export Delta water for domestic water supply because of the TDS build up in domestic waste waters that limits the ability to recharge these reclaimed waste waters to ground water basins, especially in Southern California. Salts are also of concern to the use of Delta waters for agricultural purposes. The net result is that the CVRWQCB has imposed a TMDL to control salt discharges to parts of the San Joaquin River watershed. The current restrictions on salt discharges from those already under control as well as other areas within the San Joaquin River watersheds could become increasingly more stringent as efforts are made to control the salt content of waters exported from the Delta to Central and Southern California. The total salt content of stormwater runoff and irrigation water releases where OP pesticide water quality BMPs is being evaluated, should be assessed to determine whether potential problems exist with the salt discharges.

**Molybdenum.** The CVRWQCB has expressed concern about the levels of molybdenum in some parts of the San Joaquin River watershed. While this appears to be a municipal waste water problem, there is need to evaluate whether molybdenum is present in ag stormwater runoff irrigation water releases at concentrations of concern to the CVRWQCB. *(add info on critical concentrations)*
Urban Chemicals of Concern. While the OP Focus Group is primarily concerned with the control of diazinon runoff in dormant sprayed orchards, many of the same issues apply to OP pesticide runoff/discharges from urban residential areas. Urban areas also face many, but not necessarily all of the above mentioned constituents of concern such as nutrients, other pesticides, etc., and the associated need to develop BMPs for their control. Of particular concern is the phase out of diazinon, within two years, and chlorpyrifos during this year, use in urban areas. There is an immediate need to begin to evaluate BMPs for control of the releases of other pesticides and nutrients from urban areas.

References


Appendix A

Guidance on Developing a Water Quality Program


Key elements of a reliable water quality study include:

- Clearly establish the objectives of the study.
- Understand the nature of “water quality,” water quality concerns, beneficial uses, and their assessment.
- Select the parameters to be measured and justify potential significance of each parameter selected.
- Examine previous studies to understand variability in each area of the waterbody to be studied.
- List factors that can influence results of the study and how they may influence the results.
- Determine the level of confidence at which the objective is to be achieved.
- For each area of the waterbody to be studied, determine the type, number and location of samples to be collected.
- Conduct a pilot study if no data are available from previous studies or if existing data are inadequate to define variability and other characteristics needed to establish a reliable study program.
- If the purpose of the study is to determine changes in water quality characteristics, select the magnitude of change that is to be detected and design the study accordingly.
- Select sampling techniques and methods of analysis to meet the objectives and level of confidence desired.
- Verify that analytical methods are appropriate for each area of the waterbody and at various seasons.
- Conduct studies to evaluate precision of sampling and analytical procedures and technique, reliability of preservation, and variability of the system.
- Critically examine the relationship between present and past studies.
- Screen data as they are collected.
- Analyze and interpret data.
Appendix B

The committee [NRC] emphasizes the importance of the following overall conclusion related to designing and implementing monitoring programs: Failure to commit adequate resources of time, funding and expertise to up-front program design and to the synthesis, interpretation, and reporting of information will result in failure of the entire program. Without this commitment, effort and money will be spent to collect data and produce information that may be useless.

Sound program design and implementation depend on the following factors:

- The goals and objectives of the monitoring program need to be clearly articulated in terms that pose questions that are meaningful to the public and that provide the basis for scientific investigation.
- Not only must data be gathered, but attention must also be paid to their management, synthesis, interpretation, and analysis.
- Procedures for quality assurance are needed, including scientific peer review.
- Because a well-designed monitoring program results in unanswered questions about environmental processes or human impacts, supportive research should be provided.
- Adequate resources are needed not only for data collection but also for detailed analysis and evaluation over the long term.
- Programs should be sufficiently flexible to allow for their modification where changes in conditions or new information suggests the need.
- Provision should be made to ensure that monitoring information is made available to all interested parties in a form that is useful to them.

Ten Steps to Strengthening the Role of Monitoring to Environmental Management
The role of monitoring in environmental decision making can be strengthened by addressing the following areas:

1. Clear guidance is necessary on how data are to be used and what types of decisions are to be made.
2. The goals established should be achievable scientifically, technologically, logistically, and financially.
3. The monitoring program should be integrated into the decision-making system, with decision points and feedback loops clearly established before the data are collected.
4. Where authority and control reside should be made explicit. Fiscal controls should be compatible with program controls and objectives.
5. Channels of communication among agencies and other participating individuals and groups should be identified and efforts made to ensure that the channels are interconnected and functional.
6. The monitoring program should integrate the regulatory data, management needs and responsibilities of the local, state, regional, and federal agencies to optimize the use of available resources.
7. Viable mechanisms should be established to involve the public and the scientific community as program participants early and often.
8. The monitoring program should include built-in mechanisms to ensure that the conclusions are communicated to decision makers and the public in terms that they can understand and act upon.
9. Monitoring programs should include mechanisms for periodic review and easy alteration or redirection of efforts when monitoring results or new information from other sources justifies a change.
10. The management action to be taken in response to both the expected results and unexpected but possible outcomes should be identified in advance.

Specific issues that need to be considered in developing/reviewing a water quality monitoring program are:

- What were the environmental quality objectives at the onset of the environmental monitoring programs?
- To what degree were the programs designed to detect some a priori change related to an environmental quality objective?
- If measurable changes were observed in contaminant or population levels, how were they interpreted in terms of changes to the ecosystem, economy, or human health?
- What are the characteristics of monitoring programs that respond to different environmental quality objectives (e.g., compliance monitoring versus environmental trends monitoring)?
- What spatial and temporal requirements were considered in designing the monitoring systems? Is there documentation of the design?
- What components of the aquatic ecosystem and contaminants were monitored? How were they selected?
- What methodologies were used? Why were they selected?
- To what extent were the monitoring programs designed to test hypotheses?
- How do monitoring objectives and strategies differ among different monitoring applications (e.g., point source versus regional, continuous versus pulse effects, etc.)?
- What was the relative emphasis among research, monitoring observations, and data analysis and synthesis? Were these approaches well integrated?
- Were cumulative and indirect effects accounted for in the technical design?
- In the evolution of the monitoring program, what steps were taken to ensure maximum value of the entire data set to chronicle changes in the environment?
- Was the monitoring designed to establish pollutant source and receptor relationships?
- Was the technical design modified as a result of monitoring results, and was the design adaptable to such changes?
- Was the design of the monitoring program constrained or influenced by actual or anticipated modeling efforts?
- Was quality assurance a functional component of the design?
- Were objective procedures followed in going from the monitoring program designed to that which was implemented?
• How did the cost and time limitations affect the implementation of the design program, and how did any effects influence statistical confidence?
• What mechanisms exist for logistical coordination of monitoring programs? Were they effectively used? How might they be improved?
• How was the quality assurance program included in the program design that was implemented?
• Were the conclusions supported by the resulting data, and were they consistent with the limitations of the design? Was the ability to detect differences adequately considered?
• What was the potential for missing subtle, indirect, or cumulative effects of multiple or long-term activities?
• What was the relevance of observed effects to human, resource, or ecosystem health?
• Were relationships between sources and receptors established for monitored pollutant loadings and contaminant levels found in the environment?
• What were the main technological constraints in the design and implementation of the monitoring program?
• To what extent were the monitoring systems structured to encourage innovation? How could the structure be improved?
• To what extent do improvements in monitoring depend on improvements in predictive technologies and field verification technologies such as those applicable to the quantitative description of the waste field, exposure concentrations, dose/response relationships, and food chain accumulation?
• What are the specific needs for new technology or transfer of existing technology in such areas as mathematical models, remote sensing, in situ instrumentation systems for measuring organic and biological response, sampling systems for particulates and bioavailable substances, and data analysis and management systems?
• Were the results of research integrated with the monitoring program results when they were analyzed?
• What methods were used to ensure reliable, timely, and powerful data analysis capability?
• To what extent were the data collected subjected to sophisticated analysis/synthesis techniques?
• How might data collection be automated and coupled with these emerging data management and analysis capabilities? Can automated expert systems of broad applicability be developed in marine environmental monitoring?
• What mechanisms exist or could be created for timely and effective transfer of data to products for decision-makers’ needs?
• What was the linkage between environmental monitoring and decision making? To what extent do regulatory requirements adapt to the present and future capabilities of monitoring, and to what extent did required monitoring adapt to changes in regulatory requirements?
• How were decisions made or influenced by the results of the monitoring programs?
• How did monitoring programs and results address regulatory needs and requirements?
• Were the results of environmental monitoring programs integrated functionally in
decision making with other environmental assessment approaches (i.e., assessments
based on existing information, predictive and conceptual environmental models,
experimental approaches, and observations and measurements of environmental
processes)?

FIGURE 4.1 The elements of designing and implementing a monitoring program.
FIGURE 4.6 Step 4: Develop sampling/measurement design.
FIGURE 4.2 Step 1: define expectations and goals of monitoring.
FIGURE 4.4 Step 2: Define study strategy.