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

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This issue of the Stormwater Runoff Water Quality Science/Engineering Newsletter is devoted to issues pertinent to **regulating excessive bioaccumulation of hazardous chemicals in edible aquatic life.** It also presents a discussion of the US EPA's recently announced approach for developing water quality criteria for protection of human health from chemicals that bioaccumulate through the aquatic food web. The bioaccumulation of hazardous chemicals in aquatic life is an issue of concern to both urban and rural stormwater runoff water quality managers.

On May 4, 2004, the San Francisco Estuary Institute (SFEI) held its Regional Monitoring for Trace Substances Annual Meeting. Over the past 10 years SFEI has been conducting the Regional Monitoring Program (RMP) for San Francisco Bay Estuary. The RMP 2004 annual report is available at http://www.sfei.org/rmp/pulse/pulse2004.html. Past years' reports are also available at http://www.sfei.org. The recent SFEI Regional Monitoring for Trace Substances Annual Meeting included a discussion of the effects of the urbanization of the San Francisco Bay watershed on pollutant loadings to the Bay, by Davis, et al. (2004). They conclude that, *"Urbanized portions of Bay Area watersheds are significant sources of most priority contaminants, including PCBs, mercury, copper, organochlorine pesticides, dioxins, diazinon, PAHs, and PBDEs."* In a presentation at the SFEI 2004 conference, Oros (2004) presented a discussion of the current knowledge on the occurrence and sources of PAHs in the San Francisco Bay Estuary. A similar presentation was made by Yee (2004) for dioxins in Bay sediments and aquatic life. Background information on Oros' presentation has been provided by Oros and Ross (2004). The Oros and Yee studies have shown that urban areas are significant sources of these potential pollutants. Based on the information provided, it is likely that similar kinds of problems would exist in waterbodies near urban areas, caused by PAHs, PCBs, PBDEs, organochlorine legacy pesticides and mercury. Many of these chemicals are of concern because they accumulate in aquatic sediments and bioaccumulate in the aquatic food web to hazardous levels in edible fish and other organisms.

Recently the popular press discussed the US EPA/US FDA warning on consumption of certain types of fish due to excessive mercury. The US EPA released the following fish consumption advisory in the US EPA's WQS-news listserver.

Subj:	**[wqs-news] Joint FDA - EPA Fish Consumption Advisory Released**
Date:	3/23/2004 10:22:37 AM Pacific Standard Time
From:	Hanlon.Edward@epamail.epa.gov
To:	wqs-news@lists.epa.gov
Sent from the Internet	

On Friday, March 19th, 2004, the U.S. Food & Drug Administration and USEPA issued a joint consumer advisory about mercury in fish and shellfish. The advice is for women who might become pregnant, women who are pregnant, nursing mothers, and young children. Aside from being issued jointly by two federal agencies, this advisory is important because it emphasizes the positive benefits of eating fish and gives examples of commonly eaten fish that are low in mercury. In the past, FDA issued an advisory on consumption of commercially caught fish, while EPA issued advice on recreationally caught fish. By following these three recommendations for selecting and eating fish or shellfish, women and young children will receive the benefits of eating fish and shellfish and be confident that they have reduced their exposure to the harmful effects of mercury:

Do not eat Shark, Swordfish, King Mackerel, or Tilefish because they contain high levels of mercury. Eat up to 12 ounces (2 average meals) a week of a variety of fish and shellfish that are lower in mercury. Five of the most commonly eaten fish that are low in mercury are shrimp, canned light tuna, salmon, pollock, and catfish. Another commonly eaten fish, albacore (white) tuna has more mercury than canned light tuna. So, when choosing your two meals of fish and shellfish, you may eat up to 6 ounces (one average meal) of albacore tuna per week. Check local advisories about the safety of fish caught by family and friends in your local lakes, rivers, and coastal areas. If no advice is available, eat up to 6 ounces (one average meal) per week of fish you catch from local waters, but do not consume any other fish during that week. For more detailed information, visit EPAs internet site at
http://www.epa.gov/waterscience/fish/
or visit
http://www.cfsan.fda.gov/seafood1.html.
You may also call the FDAs food information line toll-free at 1-888-SAFEFOOD.

In addition to concern about contaminants in marine fish, waterbodies in many areas of the US have sufficient concentrations of mercury, organochlorine "legacy" pesticides (such as DDT, chlordane, toxaphene, dieldrin, etc.), PCBs and dioxins, to cause health agencies to issue local fish consumption advisories. In many of the areas where excessive bioaccumulation of hazardous chemicals is occurring in local waterbody fish, this bioaccumulation is associated with stormwater runoff of the hazardous chemical from land sources. Newsletter NL 6-4 presented a summary from a report by Lee and Jones-Lee (2000) covering the excessive bioaccumulation of organochlorine legacy pesticides and PCBs in fish taken from the Central Valley of California. As discussed, DDT and several other formerly used organochlorine pesticides are still present in stormwater runoff from agricultural areas where these pesticides were formerly used.

National Forum on Contaminants in Fish

In late January 2004 the US EPA, the California Office of Environmental Health Hazard Assessment (OEHHA) and the Agency for Toxic Substances and Disease Registry (ATSDR) held the 2004 National Forum on Contaminants in Fish. Information on this meeting is available at
http://www.epa.gov/waterscience/fish/forum/2004/com.htm.
The presentations at this meeting are available Summaries of past Forums is available at
http://www.epa.gov/waterscience/fish/forum/2004/agenda.htm.

The focus of this meeting was the excessive bioaccumulation of mercury, where several presentations were made on the occurrence of excessive mercury in edible fish and shellfish. Information was also presented on bioaccumulation of organochlorine pesticides, PCBs and arsenic. While not part of the official 2004 Forum program, Lee and Jones-Lee (2004) made available as a handout a set of PowerPoint slides which represented a summary of the Lee and Jones-Lee (2002) report on excessive bioaccumulation of organochlorine pesticides and PCBs. These slides are available at http://www.members.aol.com/duklee2307/OCl-slides-SanDiego.pdf

Background Information on Bioaccumulation

The excessive bioaccumulation of hazardous chemicals in edible aquatic life is such a national problem to cause the US EPA to develop guidance documents for regulating excessive bioaccumulation of hazardous chemicals. Presented below is a section of a recent US EPA (2003) report on the excessive bioaccumulation issue. This section provides an overview of the US EPA's approach for establishing excessive bioaccumulation based water quality criteria.

1. Introduction[1]

In 2000, the U.S. Environmental Protection Agency (EPA) published the Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (USEPA, 2000a). That document (referred to here as the 2000 Human Health Methodology) presents technical guidance and the steps that EPA will follow for deriving new and revised national recommended ambient water quality criteria (AWQCs) for the protection of human health under Section 304(a) of the Clean Water Act. The 2000 Human Health Methodology includes guidance on chemical risk assessment, exposure, and bioaccumulation. To supplement the 2000 Human Health Methodology, EPA is developing series of Technical Support Documents (TSD) on Risk Assessment, Exposure Assessment, and Bioaccumulation. The first volume, (Volume 1: Risk Assessment; EPA-822-B-00-005), was published with the 2000 Methodology in October 2000. Recently the US EPA has released (Volume 2) of the Technical Support Document (TSD) focuses on the technical components of the 2000 Human Health Methodology that pertain to the assessment of chemical bioaccumulation.

The 2000 Human Health Methodology incorporates a number of scientific advancements made over the past two decades. One of these advancements is in the assessment of chemical exposure to humans through the aquatic food web pathway. For certain chemicals, exposure via the aquatic food web is more important than exposure from ingestion of water. Such chemicals tend to be highly hydrophobic, to partition in aquatic environments to surficial sediments, and to accumulate in high concentrations in fish and shellfish through the process of bioaccumulation.

One method for incorporating chemical exposure to humans through the aquatic food web involves estimating the amount of a chemical expected to bioaccumulate in fish and shellfish that are commonly consumed by populations in the United States. Previously, EPA primarily used bioconcentration factors (BCFs) to estimate chemical accumulation of waterborne chemicals by aquatic organisms. The BCF reflects contaminant exposure and accumulation by fish and shellfish only through the water column. Over the past two decades, however, science has shown that all the routes (e.g., food, sediment, and water) by which fish and shellfish are exposed to highly bioaccumulative chemicals may be important in determining the chemical accumulation in the organism's body, and that these chemicals can be transferred to humans when they

[1] US EPA, "Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Technical Support Document Volume 2: Development of National Bioaccumulation Factors, United States Office of Water EPA-822-R-03-030 Environmental Protection Office of Science and Technology, December (2003)

consume contaminated fish and shellfish. The EPA's approach to estimating uptake into fish and shellfish now emphasizes the use of a bioaccumulation factors (BAFs), which account for chemical accumulation from all potential exposure routes. The generalized ambient water quality criterion (AWQC) formula for noncancer effects is shown below (Equation 1-1) as an example of how the BAFs are used in the calculation of a recommended national AWQC for the protection of human health (USEPA, 2000a). In Equation 1-1, trophic-level specific BAFs are used in the denominator, along with information on the amount of fish consumed on a daily basis (FI) for each trophic level (i), to estimate human exposure to contaminants through the aquatic food web.

$$AWQC = RfD \cdot RSC \cdot \left(\frac{BW}{DI + \sum_{i=2}^{4} (FI_i \cdot BAF_i)} \right) \quad \text{(Equation 1-1)}$$

where:
RfD = reference dose for noncancer effects (mg/kg/day)
RSC = relative source contribution to account for nonwater sources of exposure
BW = human body weight (kg)
DI = drinking water intake (L/day)
FI = fish intake (kg/day) at trophic level i (i = 2, 3, 4)
BAF*i* = bioaccumulation factor (L/kg) at trophic level i (i = 2, 3, 4)

1.1 PURPOSE

This TSD volume:

- Presents the technical basis for the EPA's approach to developing national BAFs for the different trophic levels of fish and shellfish commonly consumed by humans,
- Discusses the underlying assumptions and uncertainties inherent in the approach, and
- Provides further detail on applying the BAF component of the 2000 Human Health Methodology.

As indicated in Equation 1-1 of Section 1, the national, trophic level–specific BAFs for a given contaminant are used by the EPA in the derivation of AWQC for the protection of human health. A subsequent volume (Volume 3: Development of Site-Specific Bioaccumulation Factors) provides guidance to States and authorized Tribes for developing site-specific BAFs for the various trophic levels when BAFs that are more representative of local conditions are preferred. Neither of the bioaccumulation TSDs should be used alone to derive BAFs, but rather in conjunction with the 2000 Human Health Methodology. The intended audience for both of these documents includes the EPA scientists who are responsible for deriving water quality criteria, State and Tribal risk assessors and stakeholders interested in the technical basis of EPA's national BAF methodology, and other users interested in bioaccumulation issues for other applications.

1.2 SCOPE

The goal of EPA's approach for developing national BAFs is to represent the long-term average bioaccumulation potential of a pollutant in aquatic organisms that are commonly consumed by humans throughout the United States. National BAFs are not intended to reflect fluctuations in bioaccumulation over short periods (e.g., a few days) because human health AWQCs are generally designed to protect humans from long-term exposures (over a lifetime) to waterborne chemicals. National BAFs are also intended to account for some major chemical, biological, and ecological attributes that can affect bioaccumulation in bodies of water across the United States.

For this reason, EPA's approach includes separate procedures for deriving national BAFs according to the type of chemical (e.g., nonionic organic, ionic organic, inorganic, and organometallic). For the purposes of the 2000 Human Health Methodology, nonionic organic chemicals are defined as organic compounds that do not ionize substantially in natural bodies of water. These chemicals are also referred to as "neutral" or "nonpolar" organics in the scientific literature. Ionic organic chemicals are considered to include those chemicals that contain functional groups with exchangeable protons, such as hydroxyl, carboxylic, and sulfonic and nitrogen (pyridine) groups. Ionic organic chemicals undergo ionization in water, the extent of which depends on the pH and the pKa of the water. Ionic chemicals are considered separately when deriving national BAFs because the behavior of the anionic or cationic species of these chemicals in aquatic systems is much different from those of their neutral (un-ionized) counterparts. Inorganic and organometallic chemicals include inorganic minerals, other inorganic compounds and elements, metals, metalloids, and organometallic compounds. This TSD document focuses primarily on the procedures for determining BAFs for nonionic organic chemicals that bioaccumulate. The procedures for estimating bioaccumulation of nonionic organic chemicals are generally better developed than those for ionic chemicals. Therefore, both the conditions under which these procedures can be applied and the limitations associated with their application warrant further explanation. In addition, EPA's national BAFs are derived separately for each trophic level to account for potential biomagnification of some chemicals in aquatic food webs and broad physiological differences among organisms that may influence bioaccumulation. As discussed in Chapter 3, lipid contents of aquatic organisms and the amounts of organic carbon in ambient waters affect bioaccumulation of nonionic organic chemicals in aquatic food webs. National trophic-level specific BAFs incorporate adjustments for the lipid content of commonly consumed fish and shellfish and for the freely dissolved fraction of the chemical in ambient water by using nationwide averages for these two parameters. Further discussion of these parameters is provided in Section 4.

1.3 IMPORTANT BIOACCUMULATION AND BIOCONCENTRATION CONCEPTS

Several attributes of the bioaccumulation process are important to understanding the approach used to develop national BAFs used in setting national recommended AWQCs for the protection of human health. First, the term *bioaccumulation* refers to the uptake and retention of a chemical by an aquatic organism from all surrounding media (e.g., water, food, sediment). The term *bioconcentration* refers to the uptake and retention of a chemical by an aquatic organism from water only. For some chemicals (particularly those that are highly persistent and hydrophobic), the magnitude of bioaccumulation by aquatic organisms can be substantially greater than the magnitude of bioconcentration. For such chemicals, an assessment of bioconcentration alone will underestimate the extent of accumulation in aquatic biota. Accordingly, EPA's 2000 Human Health Methodology emphasizes the consideration of chemical bioaccumulation by aquatic organisms, whereas EPA's 1980 Methodology emphasized the measurement of bioconcentration. Another important aspect of the bioaccumulation process is the steady-state condition. Specifically, bioaccumulation can be viewed simply as the result of competing rates of chemical uptake and depuration (chemical loss) by an aquatic organism. The rates of chemical uptake and depuration can be affected by various factors, including the properties of the chemical, the physiology of the organism in question, water quality and other environmental conditions, the ecological characteristics of the water body (e.g., food web structure), and the concentration and loadings history of the chemical. When the rates of chemical uptake and depuration are equal, tissue concentrations remain constant over time and the distribution of the chemical between the organism and its source(s) is said to be at steady state.

For constant chemical exposures and other conditions, the steady-state concentration in the organism represents the highest accumulation potential of the chemical in that organism under those conditions. The time needed for a chemical to achieve steady state in the organism has been shown to vary according to the properties of the chemical, the variability of environmental conditions, and other factors. For example, some highly hydrophobic chemicals can require long periods (e.g., many months) to reach steady state between environmental compartments, whereas highly hydrophilic chemicals usually reach steady state relatively quickly (e.g., hours to days). National recommended AWQCs for the protection of human health are typically designed to protect humans from harmful lifetime or long-term exposures to waterborne contaminants. Given this goal, assessing bioaccumulation that equals or approximates steadystate accumulation is one of the principles underlying the derivation of national BAFs. For chemicals that require relatively long periods to reach steady state in aquatic organisms, changes in the concentration of the chemical in the water column may occur much more rapidly than corresponding changes in concentrations in tissue. Thus, if the system departs substantially from steady-state conditions and water concentrations are not averaged over a sufficient time period, the ratio of the chemical concentration in tissue of organisms to that in water (i.e., the BAF) may have little resemblance to the steady-state ratio and have little predictive value for long-term bioaccumulation potential. Therefore, BAF measurements should be based on chemical concentrations in the water column, averaged over a sufficient period for the chemical of interest.

In addition, the BAFs used in deriving national recommended AWQCs for the protection of human health should be based on adequate spatial averaging of chemical concentrations in both tissue of consumed organisms and the water column. The concept of proper temporal averaging for the determination of BAFs is illustrated in Figure 1-1 (taken from Burkhard, 2003). Figure 1-1A shows the daily concentrations of a hypothetical nonionic organic chemical, using a simple dilution model and daily flow data for the Mississippi River at St. Paul, Minnesota. These daily chemical concentrations in the river can be transformed into daily chemical concentrations in fish by using the kinetic models of Gobas (1993). Figure 1-1B shows the results of these transformations in piscivorous fish for chemicals with log *n*-octanol-water partition coefficients (Kows) ranging from 2 to 9 for a simple hypothetical food web. Together, Figures 1-1A and 1-1B show that concentrations of nonionic organic chemicals in fish change over time, relative to the concentration of the chemical in the ambient water, at speeds dependent upon the hydrophobicity of the chemical, i.e., the chemical's Kow. The response is graded in magnitude, and the rate of change decreases with increasing Kow. For chemicals with low Kows (e.g., log Kows of 2 and 3), the speed of change is very fast, such that concentrations of the chemical in fish mimic the trends

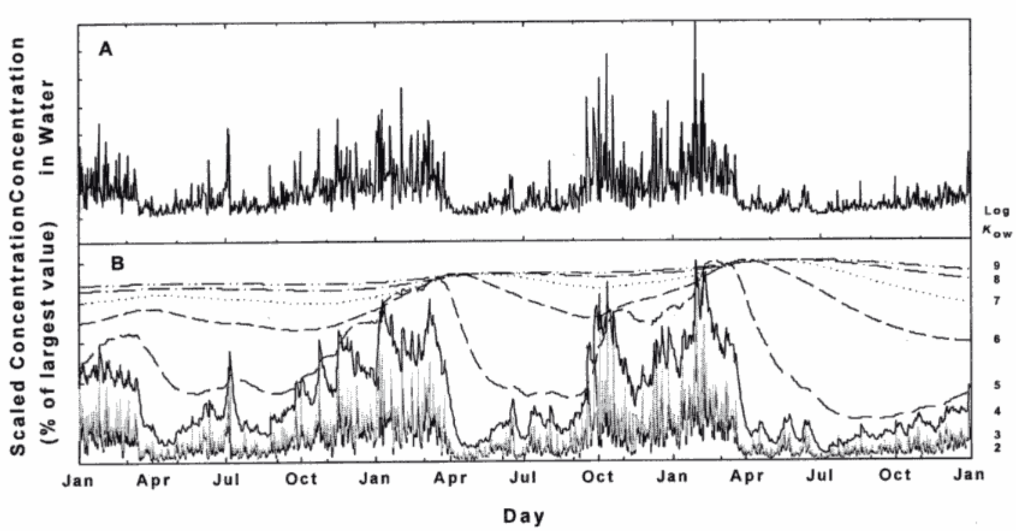

Figure 1-1 (A). Daily concentrations of a hypothetical nonionic organic chemical over time in the water column, predicted using a simple dilution model and daily flow data for the Mississippi River at St. Paul, Minnesota.
(B) Daily chemical concentrations in piscivorous fish found using the kinetic food web models of Gobas (1993) with the daily chemical concentrations in the water column for nonionic organic chemicals with log *n*-octanol-water

of the chemical concentration in ambient water. For chemicals with large Kows (e.g., log Kows of 6 and 7), concentrations of the chemical in fish change slowly relative to those in the water, and in general, the concentrations in fish follow the long-term trends for the chemical concentration in the water. Clearly, BAFs based on inappropriate temporal averaging of chemical concentrations in the water will have little predictive power; thus, BAFs should be based on concentrations in the water column that are averaged over a sufficient period of time that is appropriate for the chemical of interest. For this reason, a BAF was defined in the 2000 Human Health Methodology as representing the ratio (in liters per kilogram) of the concentration of a chemical in the tissue of an aquatic organism to its concentration in the ambient water in situations where the organism and its food are exposed and *the ratio does not change substantially over time* (i.e., the ratio reflects bioaccumulation at or near steady state). Similarly, a BCF was defined as the ratio (in liters per kilogram) of the concentration of a chemical in the tissue of an aquatic organism to the chemical's concentration in the ambient water, in situations where the organism is exposed through the water only and *the ratio does not change substantially over time*.

From the perspective of sampling for determining BAFs, chemicals with large Kows will generally require that numerous water samples be averaged over time to establish the long-term chemical concentrations in the water. In contrast, for chemicals with low Kows, because the concentrations in the fish mimic those in water, the time scale for establishing the chemical concentrations in the water shrinks to concurrent sampling of both fish and water; current chemical concentrations in the water provide a good predictor of the chemical concentration in the fish. Burkhard (2003) provides additional details on BAF sampling design and EPA will provide additional information on field sampling designs for determination of BAFs in TSD Volume 3: Development of Site-Specific Bioaccumulation Factors.
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The Lee and Jones-Lee (2002) report presents information on developing site-specific biota sediment accumulation factors based on the US EPA (2000a,b) previous publication on aquatic food web bioaccumulation issues.

Regulating Bioaccumulation

One of the primary modes of human health impacts associated with urban and rural stormwater runoff is the transport of chemicals from their point of use or discharge to the waterbody where the chemicals bioaccumulate in edible organisms to levels that are a threat to those who use these organisms as food. This pathway for exposure of people to hazardous chemicals is especially important for organochlorine compounds such as the legacy pesticides (DDT, chlordane, dieldrin, toxaphene), PCBs and dioxins, as well as mercury.

In the 1970s the US EPA (1976) adopted the worst-case-based water quality criteria development approach for bioaccumulatable chemicals, in which the greatest bioaccumulation factor found in any waterbody is used as the national criterion to establish a critical concentration in water. It has been well known since the 1970s (see Lee and Jones-Lee, 1996; AFS, 1979) that this approach can greatly overestimate the amount of actual bioaccumulation that will occur in aquatic life in many, if not most, waterbodies. The American Fisheries Society Water Quality Section (AFS, 1979) devoted to discussing the US EPA (1976) "Redbook" PCB criterion indicated that the amount of bioaccumulation of PCBs was dependent on the characteristics of the waterbody. Waterbodies with high suspended particulates could have much higher concentrations of PCBs without excessive bioaccumulation in edible fish than waterbodies with low suspended solids (Veith, et al., 1978). Lee and Jones-Lee (2002)
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have discussed the unreliability of trying to use worst-case-based bioaccumulation factors to regulate bioaccumulatable pollutants, such as mercury or the organochlorine pesticides and PCBs. They recommend that the US EPA's recommended approach of developing a site-specific bioaccumulation factor be evaluated, where the concentrations of total and dissolved forms of the pollutant of concern in water and in sediments are related to aquatic life edible tissue residues.

Bioaccumulation of a chemical is dependent on a partitioning between the water, suspended and deposited sediments and the aquatic organisms. Food web accumulation from lower to higher trophic levels (i.e., phytoplankton, zooplankton, small fish, large fish) can and usually does play a major role in accumulation of hazardous chemicals in edible organisms. Lee recommends that national bioaccumulation factors not be used and that site-specific bioaccumulation factors be developed for a particular waterbody, in order to properly relate excessive tissue concentrations (based on a human health risk assessment and a certain fish or organism consumption rate) to water concentrations. It has been understood by some since the 1970s that, for those potential pollutants that have an important bedded sediment component of the bioaccumulation pathway, water concentrations based on dissolved and/or total concentrations are not likely reliable indicators of potential bioaccumulation. This arises out of the fact that the processes that control the release/uptake of hazardous chemicals that tend to bioaccumulate in edible organisms are dependent on a variety of sediment-related factors which are not easily characterized. For example, for mercury, methylation of mercury tends to occur under anoxic (oxygen-free) conditions associated with sulfate-reducing bacteria using organic matter as a source of energy to reduce sulfate to sulfide. The processes that control methylation of mercury are not adequately understood so that predictions can be made based on the characteristics of the sediments and water, as to the extent that methylation will occur in a particular situation.

The Sacramento River Watershed Program, organized by the California Central Valley Regional Water Quality Control Board, organized the Delta Tributaries Mercury Council (DTMC). The Council consists of stakeholders interested in the mercury pollution problems associated with former mercury mining in the Coast Range of California and gold mining in the Sierra-Nevada Mountains. These mining activities have left large amounts of mercury exposed to the environment, which is being converted to methylmercury and bioaccumulating in fish and other organisms to excessive levels that are a threat to the health of fetuses and young children. Many of the major waterbodies in the Central Valley of California, including San Francisco Bay, have been polluted by mercury from former mining activities. This has stimulated the California Bay-Delta Authority to fund in excess of $20 million in research devoted to understanding the sources of the mercury, its transformations and impacts.

Recently a DTMC meeting was held in which Dr. Darell Slotten and Dr. Chris Foe presented summaries of some of their work on the mercury problem in waterbodies of the Central Valley of California. The focus of this work was to gain an understanding of the relationships between water concentrations of mercury in its various forms and the concentrations that are found at various trophic levels in several different Central Valley waterbodies. Drs. Slotton and Foe's reports, which served as the basis for their presentations (as well as reports from other investigators) are available at

http://loer.tamug.tamu.edu/calfed/DraftReports.htm

Both Slotton and Foe reported that the current understanding of the relationship between water concentrations of mercury, whether total or dissolved, and the concentrations in various trophic levels in the aquatic food web, are poorly understood, and while site-specific bioaccumulation factors can be developed for a limited area, there are a variety of factors that influence the magnitude of bioaccumulation that occurs in a particular area. This appears to be related to the lack of understanding of the aqueous environmental chemistry of mercury in aquatic systems, with particular reference to how mercury in various forms added to a waterbody is converted to methylmercury.

As discussed by Lee and Jones-Lee (2002), the US EPA is finally leaning toward regulating bioaccumulatable chemicals based on tissue residues in edible aquatic life. Adopting this approach, however, will require that, for regulatory purposes, a concentration of the pollutant of concern is measurable in water and in various sources of the pollutant, in order to establish discharge limits and ambient water allowable concentrations. As a result of this approach, it will be necessary to be able to relate water concentrations to excessive bioaccumulation.

Overall, the regulation of bioaccumulatable chemicals, such as mercury, organochlorine legacy pesticides, PCBs, dioxins, etc., from various sources and in various waterbodies, is still a long way from being conducted in a technically valid, cost-effective manner. There is need for considerable research devoted to developing site-specific bioaccumulation factors for various types of waterbodies under various conditions that exist in an area. This research, however, must be accompanied by detailed, appropriately conducted aquatic chemistry studies to understand the relationship between the total concentration of a constituent in water and its bioaccumulation to excessive levels in edible organisms.

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