Preliminary Assessment of the Bioaccumulation of PCBs and Organochlorine Pesticides in *Lumbriculus variegatus* from City of Stockton Smith Canal Sediments

and

Toxicity of City of Stockton Smith Canal Sediments to *Hyalella azteca*

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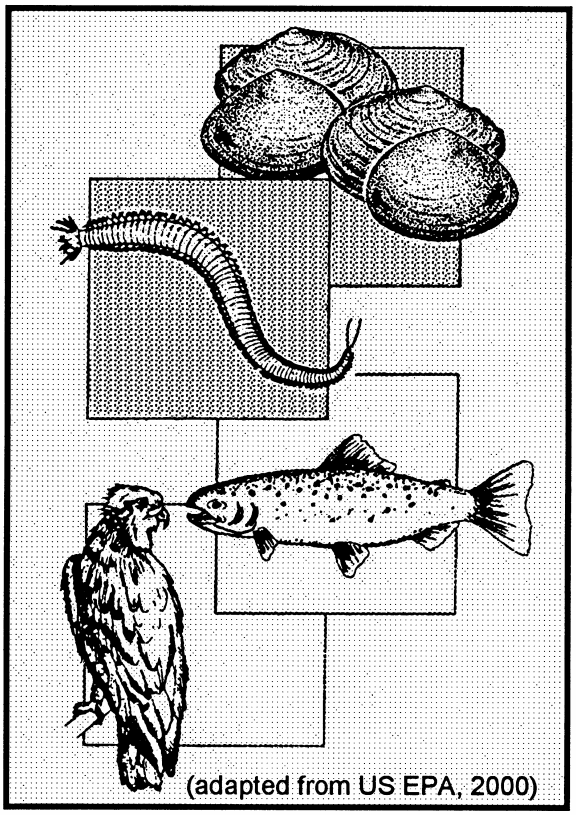

Report to the DeltaKeeper
Stockton, California
and the
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Executive Summary

White catfish and largemouth bass taken from Smith Canal in the city of Stockton have been found to contain sufficient concentrations of PCBs to be a threat to cause cancer in those who use these fish as a regular source of food. These fish contained about 100 ng/g wet weight of the PCB Aroclors which is about five times the allowed screening value for protection of humans who use PCB contaminated fish as food. This finding has prompted a pilot study of the potential role of the Smith Canal sediments as a source of the PCBs that are bioaccumulating to excessive levels in edible Smith Canal fish. It has been found that a Yosemite Lake sediment sample (which is located at the upstream end of Smith Canal) contained about 1,000 ng/g dry weight of PCB congeners and Aroclors. Samples of Smith Canal sediments taken at about midway between Yosemite Lake and the mouth of Smith Canal ("Mid") contained about half (400 ng/g) the PCBs as the Yosemite Lake sediments. The Smith Canal sediment taken near the mouth of the canal where it discharges to the San Joaquin River Deep Water Ship Channel ("Mouth") had a lower concentration (12 ng/g) of PCBs, indicating that the source of PCBs was likely from storm sewers that drain several areas of Stockton into Yosemite Lake.

The Yosemite Lake sediment sample had a total organic carbon (TOC) content of about 5.8% with the Mid-Canal (3.5%) and Mouth (0.5%) sediments having lower TOC content. This elevated concentration of TOC would make the PCBs in Yosemite Lake sediments less bioavailable than those associated with lower levels of TOC. Incubation of *Lumbriculus* (an oligochaete-worm) in the Smith Canal sediment samples, following the US EPA standard bioaccumulation testing procedure, showed that at least some of the PCBs were bioavailable, with exposure to Yosemite Lake sediment resulting in a 310 ng/g concentration (wet weight) in the worms after the 28-day incubation period. Lower amounts of PCBs (Mid 161 ng/g and Mouth 72 ng/g) were taken up by this worm from the Mid and Mouth sediment samples. The elevated TOC concentration of the Yosemite Lake sediment sample did not prevent some of the PCBs in this location sediments from bioaccumulating in the test worm.

While the Smith Canal sediments contained several OCl pesticides, especially chlordane and DDT, only chlordane (15 ng/g) and several of the DDT transformation products (123 ng/g) were taken up by *Lumbriculus*. There was also uptake of nonochlor from the sediments to 6 ng/g. At this time the known primary bioaccumulation problem in Smith Canal is due to PCBs and does not include the OCl legacy pesticides.

The Yosemite Lake sediments were also found by Pacific EcoRisk to be toxic to the benthic amphipod *Hyalella azteca* with 40% mortality in the 10-day test. The Mid and the Mouth Smith Canal sediments were nontoxic to *Hyalella*. The US EPA Mid-Continent Ecology Division located in Duluth, MN found, in testing a split of the same Yosemite Lake sediment sample, about 60% mortality of *Hyalella*.

This pilot sediment bioaccumulation study has demonstrated that the US EPA standard bioaccumulation testing procedure is a useful, readily implementable approach to determine the bioavailability of potentially bioaccumulatable sediment-associated chemicals. This testing procedure

should become part of the procedures that are used in developing management programs for excessive bioaccumulation problems.

Further studies are needed to define the magnitude of the excessive PCB bioaccumulation problem in edible fish taken from Smith Canal. These include additional fish sampling to confirm and establish the magnitude of the excessive PCB bioaccumulation problem in Smith Canal. If confirmed, then a comprehensive sediment sampling and PCB analysis program should be conducted. Also, additional studies on the uptake of the PCBs by *Lumbriculus* from Yosemite Lake sediments should be conducted.

Forensic studies, using PCB analysis of existing storm sewer sediments of the city of Stockton, should be used to attempt to determine the source of the PCBs that have accumulated in Yosemite Lake sediments. A likely source was one or more industrial facilities that dumped/discharged PCBs in the Stockton storm sewer system. Another possible source was a possible electrical transformer spill of PCBs that entered the storm sewer system that conveyed the PCBs to Smith Canal.

One of the objectives of these additional studies should be to establish a site-specific biota sediment accumulation factor for the dominant edible fish species and the sediment taken from Yosemite Lake. This value will be important in determining the initial sediment remediation objective associated with a program to control the excessive bioaccumulation of PCBs in Smith Canal fish that are derived from Yosemite Lake sediments.

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Acronyms and Abbreviations

BASS	Bioaccumulation and Aquatic System Simulator
BSAF	biota sediment accumulation factor
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region (RWQCB)
CWA	Clean Water Act
DFG	California Department of Fish and Game
DO	dissolved oxygen
EC	electrical conductivity
ft	feet
g	grams
m^2	square meters
mg/L	milligrams per liter
mi	miles
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
N	nitrogen
ng/g	nanograms per gram
ng/L	nanograms per liter
NH_3	un-ionized ammonia or ammonia, which is the sum of NH_3 plus NH_4^+
nitrate-N	nitrate-nitrogen
NOAA	National Oceanic Atmospheric Administration
O_2	oxygen
OCls	organochlorine pesticides and PCBs
PCBs	polychlorinated biphenyls
PI	principal investigator
QA/QC	quality assurance/quality control
RWQCB	Regional Water Quality Control Board, Central Valley Region
SFEI	San Francisco Estuary Institute
SWRCB	State Water Resources Control Board
TIE	toxicity identification evaluation
TMDL	total maximum daily load
TOC	total organic carbon
US EPA	US Environmental Protection Agency
USGS	US Geological Survey

Bioaccumulation of OCls in Smith Canal Organisms

Introduction

The excessive bioaccumulation of organochlorine pesticides, such as DDT, dieldrin, chlordane, toxaphene, etc., in aquatic life is a significant problem in the Central Valley of California to both human and ecological receptors. The Central Valley Regional Water Quality Control Board (CVRWQCB) (SWRCB, 1998) has listed 11 waterbodies as 303(d) "impaired" due to excessive concentrations of organochlorine pesticides and/or polychlorinated biphenyls (PCBs). The organochlorine pesticides are sometimes termed "legacy" pesticides, since, while they were extensively used in the Central Valley in agriculture and urban areas, this use was terminated over 20 years ago because of the threat to cause cancer that these chemicals represent to human health. However, due to certain characteristics of their chemical structure, these compounds are highly resistant to biotic and abiotic degradation, and persist, particularly in soils and aquatic sediments, in ecosystems around the world. There was also concern about the effects of these pesticides on wildlife, especially fish-eating birds. Studies by the USGS (Brown, 1998) have shown that DDT and some of the other legacy pesticides are currently present in stormwater runoff from agricultural fields in the San Joaquin River watershed at concentrations that represent a threat to bioaccumulate to excessive levels in edible fish.

PCBs were industrial chemicals that were widely used for a variety of manufacturing processes. While not pesticides, they have similar structure to the organochlorine pesticides. Polychlorinated biphenyls (PCBs) refer to a group of 209 chlorinated biphenyl compounds (congeners), based on the position for the substitution of chlorine on the biphenyl molecule – biphenyl being two benzene rings linked together. PCBs were widely used in electrical transformers and capacitors, hydraulic fluids, lubricating oils, inks, plasticizers and for a variety of other purposes. They were used in the US from 1929 until they were banned in 1979. Many of the PCBs are highly resistant to environmental degradation and have a strong tendency to bioaccumulate in aquatic life. PCBs are not particularly acutely toxic to aquatic life, although there is concern about long-term chronic toxicity issues. The PCBs have traditionally been evaluated as an Aroclor mixture, although as analytical techniques have become more sophisticated, they are increasingly being evaluated on a congener basis. For this report, the legacy organochlorine pesticides and the PCBs are grouped as organochlorines (OCls).

The CVRWQCB/SWRCB has been monitoring edible fish tissue in Central Valley waterbodies for organochlorine pesticides, mercury and some other constituents. A study funded by the DeltaKeeper through the Port of Stockton lawsuit settlement ($75,000) along with some supplemental funding ($20,000) from the CVRWQCB was conducted by the San Francisco Estuary Institute (SFEI). This monitoring (SFEI, 2001) revealed that fish taken from Smith Canal in the city of Stockton contained sufficient concentrations of PCBs to be a threat to cause cancer in those who routinely use these fish as food. This was somewhat surprising, in that elevated concentrations of PCBs are normally present in areas where there has been significant industrial activity, with associated discharge of wastewaters containing these chemicals. PCBs have been extensively used as heat exchange fluids in electrical transformers. Another source of PCBs is leakage from or spills of PCB transformer fluid that reaches a water course. In an effort to explore this matter further, the DeltaKeeper acquired US EPA 319(h) funding to determine whether the PCBs that were found in Smith Canal fish could be derived

from Smith Canal sediments. Based on the limited funding available, this study was designed to be a pilot study to provide introductory information on this issue. It was also designed to explore the use of a benthic oligochaete (*Lumbriculus variegatus*) as a test organism that could be used to evaluate whether Central Valley aquatic sediments contained OCls in bioavailable forms.

Approach

This OCl bioaccumulation project evolved from an ongoing study of the role of the city of Stockton Smith Canal sediments as a source of the excessive PCBs that have been found in fish taken from Smith Canal. On behalf of the DeltaKeeper and the CVRWQCB, the Smith Canal sediment study project PI (G. F. Lee) organized and supervised a pilot study devoted to determining if the sediments in the city of Stockton Smith Canal are a potential source of the excessive bioaccumulation of PCBs that have been found in fish taken from Smith Canal. Smith Canal is a dead-end tidal freshwater slough located in the city of Stockton that receives stormwater runoff from the City. The normal tidal range is about 3 feet. Smith Canal is about 2.5 miles long and approximately 105 feet wide. It is a tributary of the San Joaquin River Deep Water Ship Channel and the Delta. It begins at Yosemite Lake, which is approximately 400 feet wide by 900 feet long. Smith Canal and Yosemite Lake are areas of intense recreational use by City residents, including sportfishing.

This study was funded by a small ($10,000) US EPA 319(h) grant to the DeltaKeeper and CVRWQCB funds ($4,000). The study involved the cooperative efforts of the DeltaKeeper (William Jennings) for sample collection, Dr. Scott Ogle/Stephen Clark of Pacific EcoRisk for sediment sample bioaccumulation and toxicity studies, and the California Department of Fish and Game (CA DFG) (D. Crane) for sediment and fish tissue analyses of OCl pesticides and PCBs. Further, while not part of the study, under arrangements made by Debra Denton of the US EPA Region 9, some of the Smith Canal sediments were sent to the US EPA Mid-Continent Ecology Division located in Duluth, MN, for work on development of sediment-based toxicity investigation evaluation (TIEs).

The US EPA (2000a) developed a guidance document presenting the "Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Freshwater Invertebrates." This guidance was specifically designed to assess the bioavailability of potentially hazardous chemicals in aquatic freshwater sediments. It provides sediment testing procedures for a 28-day bioaccumulation test using *Lumbriculus variegatus*, an oligochaete (worm). It also provides guidance on testing sediment toxicity using the amphipod *Hyalella azteca* and/or the midge *Chironomus tentans*. The worm was particularly useful for assessing bioavailable PCBs in sediments, where good agreement was found between the bioaccumulation from the sediments using the standard laboratory test procedures and what is found in natural populations of the worm under field conditions. The US EPA (2000a) test methods were used in this study by Pacific EcoRisk for both toxicity testing using *Hyalella* and sediment bioaccumulation of PCBs and organochlorine pesticides using *Lumbriculus*.

Sample Collection and Analysis

On September 6, 2001, sediment samples were collected from Yosemite Lake (upstream end of Smith Canal), about midway between Yosemite Lake and the mouth of Smith Canal, and near the mouth of Smith Canal. The sampling was conducted from Jordan Gold's boat, primarily by Stephen

Clark of Pacific EcoRisk and Jordan Gold of Applied Marine Sciences. William Jennings of the DeltaKeeper and G. Fred Lee were present as observers during sample collection. DeltaKeeper staff member Doug Marshall did most of the actual transfer of the sediment from the dredge to the collection containers. The samples were collected from about mid-channel using a kynar-coated stainless steel Van Veen grab. For each location, the upper 2.5 cm of the sediments from several sediment grabs were composited into a sample container. The samples were immediately transported, on ice, to Pacific EcoRisk Laboratories in Martinez, California, for processing.

Pacific EcoRisk used the US EPA standard benthic bioaccumulation test organism, *Lumbriculus variegatus* (oligochaete) (US EPA 2000a). The uptake of PCBs and other OCls from Smith Canal sediments by this oligochaete was used to determine the amount of PCBs and some other OCls in the sediments that are bioavailable for bioaccumulation. In addition, the Smith Canal sediments were tested for aquatic life toxicity using one of the US EPA standard sediment test organisms, *Hyalella azteca* (amphipod) (US EPA 2000a). While the OCls were not expected to be present at concentrations that are toxic to *Hyalella*, if toxicity was observed, then followup studies could be implemented to determine if the benthic organism assemblages are significantly altered/degraded compared to what would be expected based on habitat characteristics. The Smith Canal sediments with these characteristics would be candidates for work on determining the cause of the toxicity to *Hyalella*. Ultimately, this pilot study on Smith Canal sediments could become the basis for a sediment remediation program, where the Smith Canal sediments that are found to contain bioavailable PCBs could be considered for selective dredging or other management approaches.

The samples were analyzed for PCB congeners and Aroclors, organochlorine pesticides, total organic carbon (TOC), percent lipid in tissue and percent dry weight by the California Department of Fish and Game laboratories under the supervision of D. Crane.

The QA/QC data for the DFG analysis and the chain of custody for Pacific EcoRisk are available for review at Pacific EcoRisk or from G. Fred Lee.

Summary of Results

The results of the sample toxicity and bioaccumulation analysis are presented in Appendix A in the form of a report developed by Pacific EcoRisk with the assistance of G. Fred Lee. A discussion of these results is presented herein.

Aquatic Life Toxicity. The sediment sample collected from Yosemite Lake showed about 40 % mortality of *Hyalella* during the 10-day test period. A split sample of this same sediment was sent to the US EPA Mid-Continent Ecology Division Laboratory located in Duluth, Minnesota for toxicity investigation evaluations (TIEs). Norberg-King (2002) reported that the US EPA found 60 % mortality of *Hyalella* in the standard US EPA test for the Yosemite Lake sediment sample. No toxicity to *Hyalella* was found by Pacific EcoRisk for the Smith Canal-Mid and Smith Canal-Mouth sediment samples. Norberg-King reported that the toxicity found in the Yosemite Lake sediment sample by Pacific EcoRisk and the US EPA is a low level of toxicity that is not of sufficient magnitude to warrant attempting to determine its cause. This does not mean that this toxicity is not of water quality or

ecological significance. It means that the sensitivity of the TIE procedures available today require a higher level of toxicity in order to be able to determine its potential cause.

Sediment Characteristics. The concentrations of total organic carbon (TOC) in the Smith Canal sediment samples were about 5.8 % for Yosemite Lake, 3.5 % for Smith Canal-Mid and 0.5 % for Smith Canal-Mouth. This range of TOC is typical of the range that is experienced with freshwater sediments, with the Yosemite Lake sediments being on the high end of the range.

The Smith Canal Yosemite Lake sediment was found to contain a sum of the PCB congeners at ~1,000 ng/g (dry weight), the Smith Canal-Mid at ~379 ng/g, and the Smith Canal-Mouth at 12 ng/g. When this sediment was analyzed for PCB Aroclors, Aroclor 1248 was not detected (with a reporting limit of 25 ng/g), while 1254 was detected at 333 ng/g, and 395 ng/g for the duplicate analysis. PCB 1260 was detected at 816 ng/g, and 953 ng/g for the duplicate analysis. Therefore, the sum of the Aroclors is about 1,250 ng/g. This compares favorably to the sum of the congeners of about 1,000 ng/g.

The concentrations of PCB congeners and Aroclors in the Smith Canal-Mid sample were ~400 ng/g – i.e., a little less than half that found in the Yosemite Lake sample. The Smith Canal-Mouth sediment sample sum of the Aroclors was less than the reporting limit of 14 ng/g; the sum of the congeners was ~12 ng/g.

Lumbriculus *Bioaccumulation.* Exposing *Lumbriculus* to the Yosemite Lake sediment sample during the 28-day test resulted in a PCB Aroclor 1254 uptake to 180 ng/g, and Aroclor 1260 to 130 ng/g, for a sum of 310 ng/g. The sum of the congeners taken up by the worms was ~290 ng/g for the Yosemite Lake sediment sample. Again, there was good agreement between the sum of the Aroclors and the sum of the PCB congeners.

For *Lumbriculus* uptake from the Mid-Canal sediment, the sum of the PCB congeners was ~161 ng/g, and the sum of the Aroclors was 168 ng/g. For the Smith Canal-Mouth sediments, the sum of the PCB congeners was 72 ng/g, and the sum of the Aroclors was 83 ng/g.

Chlordane, DDT and some of its transformation products, and nonochlor were taken up by *Lumbriculus* from the Yosemite Lake sediment sample, where the sum of the chlordanes (cis and trans) was ~15 ng/g, and the sum of the DDTs was ~123 ng/g, with DDD,p,p' and DDE,p,p' being the dominant species. The sum of the nonochlors (cis and trans) was ~6 ng/g.

Discussion

The San Francisco Estuary Institute, under the leadership of Dr. Jay Davis, has done extensive work on organochlorine pesticide and PCB bioaccumulation in San Francisco Bay and Delta tributary fish. A summary of this work was published in the *Regional Monitoring News*, Summer 2001. Greenfield (2001) has summarized the studies that were conducted in 1998. Samples of fish were taken from 19 sites during the summer of 1998. The OCl concentrations found in these fish tissues were compared to screening values indicative of adverse effects to humans resulting from consumption

of the fish. The screening values are listed in Table 1. These screening values were based on values developed by the San Francisco Regional Water Quality Control Board, which utilized information developed by the US EPA Region 9. They are the same values as used by the US EPA (2002a) in the Agencies evaluation of excessive OCls in Orange County, CA Upper Newport Bay and its tributary fish. These are the same as the OEHHA values.

Table 1
Fish Tissue Screening Values

Chemical	Screening Value (ng/g) (wet weight)
Sum of PCB Aroclors	20*
Sum of DDTs	100
Sum of Chlordanes	30
Dieldrin	2
Diazinon	300
Chlorpyrifos	10,000
Toxaphenes	30
Endosulfan	20,000
Endrin	1,000
Lindane	30
Hexachlorobenzene	20
Mirex	1,000

* screening value is for sum of Aroclors; data presented by SFEI are sum of congeners. The sum of the congeners may not be the same as the analysis for the sum of the Aroclors, but is an indication of potential problems.

According to Davis, *et al.* (2000),

> *"The US EPA (1995) defines screening values as concentrations of target analytes in fish or shellfish tissue that are of potential public health concern. Exceedance of screening values should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted. Screening values were taken from OEHHA (1999) or calculated following U.S. EPA (1995) guidance and using the consumption rate (21 g/day)* [about one meal per week] *employed by OEHHA (1999)."*

The magnitude of a screening value is dependent on the assumed rate of fish consumption (meals/week) and the "allowed" cancer risk used in computing the value. For example, the US EPA (1995) uses an "allowed" cancer risk of one additional cancer occurring in a million people who consume fish with the screening value concentration at the rate of one meal per week over their lifetime. OEHHA (1999) uses an "allowed" cancer risk of one in one hundred thousand. Changing the "allowed" cancer risk from one in a million to one in one hundred thousand changes the screening value by a factor of 10.

According to Jennings (pers. comm., 2002), the San Joaquin County Department of Health has issued a "no consumption advisory" for the Stockton Deep Water Ship Channel based on the US EPA sediment analysis of the McCormick & Baxter Creosoting Co. Superfund site. There are "no-consumption" signs posted along the Channel near this Superfund site to warn fisherman of the hazards of eating fish taken from the Channel near Stockton, due to the presence of PAHs. For further information on this site, contact US EPA (2002b).

Greenfield reported that the concentrations of DDT and PCBs appeared to be somewhat lower in 1998 than in the 1980s. This relationship is not clear, since there may have been changes in the analytical methods over time, which may be the cause or part of the cause of the apparent decline in DDT concentrations in white catfish taken from the early 1980s through 1998. The complete SFEI report is available at http://www.sfei.org/deltafish/dfc.pdf.

The SFEI sampling for fish that took place in the summer of 1998 focused on largemouth bass and white catfish. The results from the sampling of 19 sites showed that PCB concentrations in the fish were above the screening value for potential human health effects in 30 % of the samples. It also indicated that there were localized PCB hot spots, where the concentrations were higher than in surrounding areas. The concentrations of DDT exceeded the screening value in 23 % of the samples. Other contaminants of concern with respect to bioaccumulation were dieldrin, toxaphene, arsenic, PAHs, and dioxins. Sampling of San Francisco Bay and Delta fish during 1994 to 1997 showed elevated concentrations of methylmercury, PCBs, organochlorine pesticides, and dioxins. This resulted in an interim fish consumption advisory for the Bay-Delta. The current version of this advisory states,

- *"Adults should limit consumption of Bay sport fish, and striped bass and sturgeon from the Delta to, at most, two meals per month.*
- *Adults should not eat any striped bass over 35 inches (89 cm).*
- *Pregnant women or women that may become pregnant or are breast-feeding, and children under 6 should not eat more than one meal per month, and should not eat any meals of shark over 24 inches (61 cm) or striped bass over 27 inches (69 cm)."*

The fish taken from Smith Canal as part of the SFEI study (Davis, *et al.*, 2000) were found to contain greatly elevated concentrations of PCBs, with white catfish containing 102 ng/g and largemouth bass containing 112 ng/g. These values are well above the 20 ng/g screening value for the sum of the PCBs. Smith Canal fish had the highest concentrations of PCBs of any of the 19 locations sampled in the Delta and the San Joaquin River/Sacramento River. Smith Canal is a hot spot for PCBs. Samples of *Corbicula* (a freshwater clam) taken from the Port of Stockton were found to contain total PCBs of 112 ng/g. The Davis, *et al.* (2000) study indicated that there was a positive relationship between the percent lipid content of the largemouth bass and the PCB concentration for the Port of Stockton. The high concentrations of PCBs in the fish taken from Smith Canal reported by Davis, *et al.* (2000) served as the impetus for conducting this pilot study on the role of the Smith Canal sediments as a source of the elevated PCBs in fish.

Table 2 summarizes the concentrations of OCls taken up by *Lumbriculus*, compared to the screening values.

Table 2
OCl Concentrations Found in *Lumbriculus* Exposed to Smith Canal Sediments, versus Screening Values for Edible Fish Tissue (ng/g) (wet weight)

	Screening Value	Yosemite Lake	Smith Canal-Mid	Smith Canal-Mouth
Sum of PCBs	20	310	168	83
Sum of DDTs	100	123.3	73.0	38.6
Sum of Chlordanes	30	15.6	9.2	2.5
Dieldrin	2	ND	ND	ND

Examination of the summary data presented above and summarized in Table 2, compared to the screening values, reveals that all three sediments tested in the current study resulted in tissue PCB concentrations well above the screening value. It is clear that the PCB/Aroclor bioaccumulation in *Lumbriculus* greatly exceeded the screening values for potential threats to human health; however, it is important to note that this is a bioaccumulation value in a worm, as opposed to edible fish tissue. The translation from worm concentrations to edible fish tissue concentrations is not well-understood.

The screening value for the sum of DDTs is 100 ng/g. The sum of the DDTs of 123 ng/g for the worms in Yosemite Lake sediments exceeded this value The tissue concentrations for Smith Canal-Mid was 73 ng/g and for Smith Canal-Mouth was 38.6 ng/g, which were both less than the screening value. The sum of the chlordanes screening value of 30 ng/g was not exceeded by any of the sediment samples. As for dieldrin (with a screening value of 2 ng/g), the dieldrin concentrations were all less than the reporting limit of 2 ng/g.

PCB congener profiles are useful "fingerprints" to trace sources of PCBs. According to Davis, *et al*. (2000), congeners 149, 180 and 187 are indicative of Aroclor 1260, and congeners 95, 101, 110 and 118 are indicative of Aroclor 1254. Both 1254 and 1248 (indicated by congeners 28, 44, 49 and 52) were present in the Port of Stockton largemouth bass.

The studies by Davis, *et al*. (2000) show that PCB contamination is widespread in the Central Valley, and that significant concentrations remain at some locations, such as Smith Canal, the Sacramento River in the North Delta, and the Port of Stockton. Based on the data of Davis, *et al*. (2000), it appears that there may be a temporal trend downward in some of the PCB concentrations at certain locations within the Delta and tributaries, although the data are quite scattered, and there may not be sufficient data to evaluate a trend.

DDT was canceled for use in 1972. According to SFEI, there is limited data on the use of DDT in California, since pesticide use reporting began in 1970, when DDT use was already rapidly decreasing. In 1970, 1.2 million pounds were used in California. Davis, *et al*. (2000) reported that DDT concentrations in white catfish range from a low of 42 ng/g at Smith Canal to a high of 407 ng/g in

the San Joaquin River at Bowman Road. It is of interest to find that, while DDT and its various transformation products were found at high concentrations in Yosemite Lake sediment samples, and it was bioaccumulated from these sediments by the worm, it has not been found at elevated concentrations in fish taken from Smith Canal.

Dieldrin was used on a variety of crops and for termite control for many years. Its use on food products was suspended in 1974, and all uses were banned in 1985.

Dioxins are of concern because they have a screening value of 0.3 pg/g for the ITEQs, which is the sum of the dioxins and furans. The Port of Stockton has been found in other studies to have concentrations of the sum of the dioxins above the ITEQ screening value.

From an overall point of view, it is clear that Smith Canal has a significant PCB bioaccumulation problem. The sediments of Yosemite Lake in Smith Canal have greatly elevated concentrations of PCBs and several other organochlorines. The *Lumbriculus variegatus* is able to extract elevated concentrations of PCBs and some of the pesticides from these sediments. Since other nearby areas tend to have lower concentrations, it appears that the Yosemite Lake area is a hot spot for PCB accumulation and bioaccumulation. Based on these results, there is need for further work.

Theoretical Basis for Bioaccumulation from Sediments. The US EPA (2000b) released a report, "Bioaccumulation Testing and Interpretation For the Purpose of Sediment Quality Assessment: Status and Needs." This report provides important background information on the use of bioaccumulation tests to evaluate whether contaminated sediments pose an ecological and/or human health risk. As discussed in this report,

> *"The bioavailability of contaminants in sediment is a function of the type of chemical and the chemical speciation, as well as the behavior and physiology of the organism. The two basic routes of exposure for organisms are transport of dissolved contaminants in pore water across biological membranes, and ingestion of contaminated food or sediment particles with subsequent transport across the gut. For upper-trophic-level species, ingestion of contaminated prey is the predominant route of exposure, especially to hydrophobic chemicals* [such as the organochlorine pesticides and PCBs]*."*

The bioavailability of organochlorines is controlled to a major extent through partitioning between the chemical constituent and organic matter. Those constituents with high octanol water partition coefficients (Kow) tend to bioaccumulate to a greater degree, especially in organisms with a higher lipid content. The US EPA (2000b) presents a discussion of the theoretical basis for bioaccumulation of chemicals like PCBs and the organochlorine pesticides from sediments. The following section is an extract from this report.

3.3.2.3 Biota-Sediment Accumulation Factors

In USEPA (1995b), BSAFs are defined as the ratio of a substance's lipid-normalized concentration in tissue of an aquatic organism to its organic carbon-normalized concentration in surface sediment, in situations

where the ratio does not change substantially over time, both the organism and its food are exposed, and the surface sediment is representative of average surface sediment in the vicinity of the organism.

Site-specific BSAFs (kg of organic carbon/kg of lipid) are calculated for nonpolar organic compounds using the formula

BSAF = (Ct/f1) / (Cs/foc) (4)

where Ct is the contaminant concentration in the organism (both wet and dry weight are commonly used, so moisture content should be provided whichever is used, as well as a clear delineation of which is selected), f1 is the lipid fraction in tissue, Cs is the contaminant concentration in sediment (generally dry weight), and foc is the organic carbon fraction in sediment. This lipid-normalized relationship was developed for neutral (nonionic) organic compounds and is not appropriate for inorganic substances (e.g., metals), although it has been applied to tributyltin (Eisler, 1989). This relationship is not applicable to methylmercury because methylmercury binds tightly to tissue macromolecules (Spacie et al., 1995; Bridges et al. 1996).

One of the basic premises of equilibrium-based modeling as related to sediments is the equilibrium partitioning theory (Di Toro et al., 1991). This theory is being used to propose sediment quality guidelines for two nonionic organic compounds (e.g., USEPA, 1994b), as well as for PAH mixtures and metals mixtures. The essence of the theory is that concentrations of hydrophobic chemicals in sediments are more predictive of biological effects when they are normalized to sedimentary organic carbon. Through this normalization, the concentration of these compounds in the pore water can be predicted based on Equation 5. Evidence to date indicates that chemicals that are freely dissolved in the pore water are more bioavailable than chemicals sorbed to sediments. Thus the pore water concentration, as measured or as predicted through equilibrium partitioning, is a better predictor of bioaccumulation than concentrations of chemicals on a dry weight basis in the sediment (Di Toro et al., 1991).

Cw = Cs/focKoc (5)

where Cw is the freely dissolved concentration of nonionic chemical compound in pore water, Cs is the concentration of the chemical in the sediment, foc is the fraction of sedimentary organic carbon, and Koc is the organic carbon-water partition coefficient (which can be related to Kow).

As with BAFs, BSAFs are typically derived on a site- and species-specific basis, using empirical data (USEPA, 1992a). Therefore, they incorporate the effects of metabolism, biomagnification, growth, and bioavailability. BSAFs can also be used to estimate BAFfd, as described in Cook et al. (1993) and USEPA (1995b), where BAFfd is defined as follows, where Cfd is the freely dissolved concentration of a contaminant in water:

BAFfd = Ct/Cfd (6)

Accurate information on organism lipid content and sediment TOC content is required to calculate a BSAF. Lipid content can vary considerably within a single species, based on life stage, sex, and season, so caution is necessary when attempting to use site- or species-specific BSAFs as predictors of tissue burdens in different systems. As with BAFs, proper calculation requires a reasoned approach regarding species exposure, including movement and life history as well as spatial and temporal trends.

BSAFs are most directly applied to infaunal organisms with known home range. For example, Lake et al. (1990) found that analysis of PCBs in mollusks and polychaetes at field sites representing a range of TOC and contaminant concentrations showed that BSAF calculations (i.e., lipid- and TOC-normalized concentrations) significantly reduced the variability in the raw tissue-sediment data relative to non-normalized data. Work by Hydroqual, Inc. (1995), however, has shown that lipid normalization does not always decrease the variability in BAFs (or BSAFs) and that the decision to lipid normalize and the method by which lipid normalization is achieved depend on species-specific factors as well as lipid contents.

Since ecosystems are rarely in equilibrium, BSAFs include an inherent measure of disequilibrium of the system, which can be quantified as described in USEPA (1995b). Disequilibrium is caused by kinetic limitations for chemical transfer from sediment to water, sediment to biota, or water to the food chain, as well as biological processes such as growth or biotransformation (USEPA, 1995b). Theoretically, at equilibrium BSAFs range from 1 to 4 since the ratio of Kl to (Kl/Ksoc) is thought to range from 1 to 4, where Kl is defined as the lipid-water equilibrium partition coefficient and Ksoc is defined as the sediment organic carbon-water equilibrium partition coefficient (USEPA, 1995b). However, since most systems are not at equilibrium, a wider range of BSAFs is reported. This wider range of BSAFs measured in the field does not invalidate the concept. On the contrary, it underlines the need for a field-measured BSAF that is able to incorporate disequilibrium processes (as well as exposure conditions). Several compilations of BSAFs are available, including Lee (1992), Boese and Lee (1992), and Parkerton et al. (1993), as well as a USACE Contaminants Database accessible via the Internet (McFarland and Fergusen, 1994a).

The use of site-specific BSAFs using techniques described in USEPA (1994a) is preferred. However, if literature values are used, available options include selecting a given percentile of the BSAF distribution (as in the TBP method, which uses the 94th percentile) (McFarland and Ferguson, 1994a) or using a regression equation as in the proposed Washington State guidance for sediment quality criteria for human health (PTI, 1995).

BSAFs are most useful for systems that are in steady state, which is technically defined as concentrations in sediment, water, and organisms that do not change as a function of time even though they may not reflect a thermodynamic equilibrium distribution between sediment, water, and organisms. In a practical sense, systems are often considered steady state if the concentrations do not change within the period of study. Therefore, the use of BSAFs to predict tissue concentrations might not be reliable in situations in which the chemical of interest is rapidly degraded or inputs of the chemical to the system vary. In these instances, kinetic models might be more appropriate (see Section 3.3.3.1).

Hydroqual, Inc. (1995) has developed a database of field-measured bioaccumulation factors for a variety of superhydrophobic compounds. Part of this effort involved development of a procedure whereby BAFs or BSAFs could be predicted for previously unstudied chemicals, species, or water bodies. Hydroqual concluded that within a homogeneous group of compounds (e.g., PCB congeners) BAFs and BSAFs can be predicted only within a factor of 10. The uncertainty arises from site- and species-specific differences in food web structure, partitioning at the base of the food web, and the physiology of the organisms, as well as measurement error (Hydroqual Inc., 1995). Predicting BAFs and BSAFs for chemicals outside the "homogeneous group" results in even greater uncertainty. However, results of chemical class-specific analyses in Tracey and Hansen (1996) revealed a similarity of BSAF values among species and habitat types.

The biota-suspended solids accumulation factor (BSSAF) has also been proposed for some studies. It is identical to the BSAF approach, with the exception that contaminant uptake by fish is from suspended solids, rather than in-place sediments (USEPA, 1994a). Its use has been limited.

3.3.2.4 Food Chain Multiplier

As discussed in Section 3.3.2.2, a BAF can be estimated from a BCF if the BCF is multiplied by a factor to account for food web transfer. This factor is referred to as a food chain multiplier (FCM) (USEPA, 1993a, 1995b).

BAF = (BCF)(FCM) (7)

The FCM is defined as the ratio of a BAF to an appropriate BCF (USEPA, 1995b). It has been calculated in a variety of different ways, two of which are discussed briefly below. In both approaches, FCMs are calculated assuming metabolism is negligible. USEPA (1993a) calculates FCMs using a model of the stepwise increase in the concentration of an organic chemical from phytoplankton (trophic level 1) through

the top predatory fish level of a food chain (trophic level 4) (Thomann, 1989). Thomann's model was used to generate BCFs and BAFs for trophic level 2 species (e.g., zooplankton) and BAFs for trophic level 3 and 4 species (small fish and top predator fish, respectively) over a range of chemicals with log Kow values from 3.5 to 6.5. At each log Kow value, FCMs were calculated as follows:

FCM2 = BAF2/BCF2 (8)
FCM3 = BAF3/BCF2 (9)
FCM4 = BAF4/BCF2 (10)

where FCM2, FCM3, and FCM4 are the food chain multipliers for trophic level 2, 3, and 4 species, respectively; BCF2 is the BCF for trophic level 2 organisms; and BAF2, BAF3, and BAF4 are the BAFs for trophic level 2, 3, and 4 species, respectively. Field-measured BAFs from the Great Lakes for trophic level 4 were found to be within an order of magnitude of those predicted using this approach (Thomann, 1989; USEPA, 1993a). At log Kow values of 6.5 and greater, the relationship was less certain.

The FCM is defined below as given in USEPA (1995b), where BAFfd is predicted using the Gobas (1993) bioaccumulation model. In the Gobas (1993) model disequilibrium, as discussed relative to BSAFs in the last section, is included in BAF predictions to some extent by inputting the measured concentrations of the chemical in the sediment and in the water column into the model (USEPA, 1995b).

This disequilibrium is then propagated through the food web model.

FCM = BAFfd/Kow (11)

The trophic level of an organism is needed when applying FCMs to determine BAFs. Trophic levels have traditionally been described in discrete terms as primary producers, primary consumers, secondary consumers, and top predators. Using this approach, trophic levels are symbolized by whole numbers. However, organisms have clearly defined or uniform food sources only in very rare circumstances. Typically, any organism higher in the food chain than primary consumers is likely at an intermediate trophic level, feeding on multiple trophic levels. As a result, attempting to model trophic transfer using linear food chain models introduces considerable variability into predictions of top predator tissue burdens.

Some methodologies have been developed to address trophic level issues. For example, Broman et al. (1992) have described a method to quantitatively estimate *in situ* biomagnification of organic contaminants that uses ratios of stable isotopes of nitrogen to classify trophic levels of organisms. Carbon and nitrogen isotopes are useful in characterizing an organism's trophic level because animals' metabolic processes tend to enrich the heavy isotopes of these elements, 13C and 15N (Peterson and Fry, 1987). Using this approach, significant enrichment of 15N in tissue relative to 15N in unmetabolized reference samples (i.e., in air) is indicative of increasing trophic levels.

Broman et al. (1992) have used the stable isotope approach to classify trophic levels in a littoral and a pelagic food web in the Baltic, as part of an attempt to study trophic transfer of dioxins and furans in that ecosystem. Based on their results, the authors have concluded that the isotopic method is a powerful tool for quantitatively estimating trophic biomagnification of a contaminant from field data at steady state. However, to evaluate non-steady-state conditions and the relative contributions of various exposure pathways, a more mechanistic approach, such as that described by Thomann (1989), is required. Stable isotope ratios can then be used in conjunction with a more mechanistic approach to provide more refined information on trophic pathways and consumption patterns.

(See original document for references cited in quoted text.)

It is apparent from the above discussion that factors governing bioaccumulation are far more complex than just a simple partitioning between the TOC in sediments and the lipid content of the

organism tissue. This biota sediment accumulation factor relationship should be used with caution to provide a ballpark estimate of the sediment cleanup needed, with the understanding that it is, at best, a first approximation of the coupling between sediment concentrations and organism tissue concentrations. As the sediment concentrations change, the coupling between the biota and the sediment will also likely change.

The US EPA, in an effort to improve the ability to relate sediment concentrations to bioaccumulation, has developed the Bioaccumulation and Aquatic System Simulator (BASS) model. This model uses a dynamic modeling approach to relate sediment concentrations to food web biota concentrations of hazardous chemicals like PCBs. It considers the structure of the food web, as well as the biodilution associated with higher trophic level organism growth. This modeling approach overcomes many of the inherent problems with the biota sediment accumulation factor approach for relating sediment concentrations to aquatic life tissue residues. One of the primary benefits that can be derived from using this model is the ability to predict the rate of recovery of fish tissue residues associated with a sediment remediation program. It will be important, in conducting future studies, to become familiar with this model, in order to include collection of the information needed to facilitate its use. Information on this model is available from Barber, *et al*. (2002).

The US EPA (2000a) manual, "Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment" appendix contains information on the characteristics of a number of chemicals of concern that tend to bioaccumulate. There is information on several PCBs and organochlorine pesticides. A review of this information shows, however, that it is not possible with the current information base to predict the magnitude of bioaccumulation that will occur in test organisms or higher trophic level organisms, including edible fish.

Critical Concentrations of OCls in Sediments. A common mistake made in evaluating the potential significance of PCBs and other organochlorines in sediments is the attempt to use the Long and Morgan co-occurrence-based values to infer water quality significance of the presence of PCBs and organochlorine pesticides at certain concentrations in sediments. The Long and Morgan Effects Range Low (ERL) and Effects Range Median (ERM) are not technically valid cause-and-effect values that relate the concentration of any constituent, much less PCBs or organochlorine pesticides, to effects on aquatic life. As discussed by Lee and Jones-Lee (1993,1996), the approach that was used to develop these values, which is based on co-occurrence of some type of a toxicological effect on aquatic life and a concentration of a variety of constituents, is a fundamentally flawed approach that has no technical validity. Further, and most importantly, it is inappropriate to infer, as SFEI (2002) has done in its Eco Atlas (www.ecoatlas.org/custom/ pcbtool.html), that the ERL and ERM values should have any relationship between the PCB concentrations and the quality of sediments. Bioaccumulation is not one of the response parameters that was used in developing the ERL/ERM values. If the Long and Morgan co-occurrence values had validity, it would not be for bioaccumulation - it would be for toxicity effects.

While SFEI states that the Long and Morgan co-occurrence values were developed by the National Oceanic and Atmospheric Administration (NOAA), they were actually developed by Long and Morgan, who are employees of NOAA; they are not NOAA-endorsed values. In fact, NOAA's

administration has made it clear that NOAA does not support these values. Further, O'Connor (1999a, 2002), O'Connor and Paul (2000) and O'Connor, *et al*. (1998) have shown that ERL and ERM values do not properly relate concentrations of a variety of constituents in sediments to ERL and ERM values for aquatic life toxicity. O'Connor (1999a,b), who heads the NOAA Status and Trends Program, in his review of the validity of the Long and Morgan co-occurrence values, concluded that, for many situations, flipping a coin is more reliable in predicting sediment toxicity than an ERM or ERL value.

Since PCBs have been found to have bioaccumulated in fish taken from Smith Canal, it is possible, although not necessarily proven, that the Smith Canal sediments are the source of the PCBs that have accumulated to excessive levels in the fish. It is important to understand, however, that Smith Canal is a relatively small waterbody, and that fish present in this waterbody could have acquired their PCBs from other sources. There can be little doubt that at least part of the PCBs in the fish were derived from Smith Canal sediments, based on the fact that benthic organisms, such as oligochaetes, can bioaccumulate the PCBs and some of the organochlorine pesticides from the sediments. At this time, however, there is inadequate information to predict, even for non-migratory fish that might inhabit Yosemite Lake and that part of Smith Canal throughout their whole lifetime, the degree of excessive bioaccumulation that would occur based on the concentrations of PCBs and organochlorines found in the test organisms used in the study. In order to evaluate the potential benefits of removing the sediments with elevated PCB concentrations from Smith Canal and Yosemite Lake, it would be necessary to gain a considerably better understanding of the food web accumulation of PCBs within the upper parts of Smith Canal.

Care needs to be exercised in developing OCl bioaccumulation remediation programs. It should not be assumed that the sediments with the highest concentrations of PCBs are necessarily the sediments that are the source of the PCBs or other bioaccumulatable chemicals that lead to the most elevated concentrations in organism tissue. The sediments with the highest concentrations of PCBs may bind the PCBs to the greatest extent, thereby making them less bioavailable. It could readily be that sediments with lower concentrations of PCBs, which have less binding capacity, are a more important source of the PCBs and other OCls for excessive bioaccumulation. Again, there is need for a better understanding of food web accumulation of these chemicals from the sediments to higher trophic level organisms to ensure that sediment remediation programs will be cost-effective in controlling the problem.

Background Information

There is substantial literature that serves as background to the use of *Lumbriculus* as a test organism for assessing the bioavailability of chemical constituents in aquatic sediments. An annotated bibliography of *Lumbriculus* bioaccumulation from sediments was provided to the authors by Dr. Victor McFarland of the US Army Corps of Engineers Engineering Research and Development Center Waterways Experiment Station, Vicksburg, MS. This bibliography has been included in Appendix B to aid future investigators of this problem. Additional information on these issues is provided in several papers published in the US EPA (1998) National Sediment Bioaccumulation Conference Proceedings.

Future Studies

This pilot study on the use of the US EPA standard bioaccumulation testing procedure for determining the bioavailability of sediment-associated bioaccumulatable chemicals such as the organochlorine pesticides and PCBs has demonstrated that this approach is readily implementable and can be a useful tool to assist in evaluating the potential source(s) of bioaccumulatable chemicals in a sediment. Since it is well-established that the total concentration of a chemical in sediments is not a reliable index of the bioavailability of that chemical to cause toxicity and/or to become bioaccumulated, bioaccumulation testing using *Lumbriculus* is a necessary adjunct to sediment quality evaluation.

With respect to the excessive bioaccumulation of PCBs in edible fish taken from Smith Canal, there are a number of follow-on studies that need to be conducted in order to further examine this issue. The first of these is to do additional studies of these OCls bioaccumulation within edible fish taken from Smith Canal. According to Foe (pers. comm., 2002), the CVRWQCB/SFEI has collected additional fish from Smith Canal that have not been analyzed. These fish have been stored frozen. The problem in conducting the analysis is one of contracting problems through state agencies for the analysis. Further, additional fish sampling is warranted, where representative trophic level fish that exist in the Yosemite Lake area of Smith Canal would be analyzed for the OCls. The analysis of additional fish would serve as a technical base of the information needed to list Smith Canal as a 303(d) impaired waterbody based on excessive bioaccumulation of PCBs in edible fish.

Additional sediment sampling should be done of the Smith Canal sediments near and within Yosemite Lake. Several transects of surface and below-surface sediments should be collected, especially near some of the large storm sewer outfalls that discharge to the lake. It will be important to establish the depth at which elevated concentrations of bioavailable PCBs are found in Yosemite Lake sediments. This information will be useful in determining the magnitude of the remediation program that may need to be implemented since it would determine the depth of the sediment removal that may be needed.

If elevated PCBs are found to be more associated with sediments near a particular storm sewer discharge, then sampling within the storm sewer should be done to attempt to trace, through forensic studies, the source of the PCBs. There are two likely potential sources. One of these would have been the illegal discharges from past industrial operations into the storm sewer system. When legal, PCBs were used for a wide variety of industrial processes, from manufacturing through machine cutting oils, etc. It is possible that one or more industrial facilities that discharged to a storm sewer's watershed are responsible for the PCBs that have accumulated within Smith Canal sediments, especially Yosemite Lake sediments.

The other potential source of PCBs for the Yosemite Lake area of Smith Canal would be the spill of electrical transformer oil (PCBs), which either was washed into or discharged into a storm sewer that led to Smith Canal. One of the primary uses of PCBs was as a heat exchange medium in electrical transformers. There are a number of examples of transformer leaks and spills that have resulted in substantial contamination of the environment with PCBs. The suggested forensic studies of the storm

sewer sediments could be effective in determining the specific source(s) of the PCBs that have led to Smith Canal sediment pollution.

One of the issues that will need to be addressed is that of managing the excessive PCB bioaccumulation that is occurring in Smith Canal fish. An important issue that needs to be addressed, should it be concluded that there is need to remediate Smith Canal sediments within Yosemite Lake and possibly within the storm sewer system, if they are still a source of PCBs, is the desired cleanup objective. Typically, the US EPA and state regulatory agencies are adopting a 1 mg/kg (dry weight) total PCB congener/Aroclors sediment cleanup objective. That objective is essentially the same as the concentration of total Aroclors found in the single sample of the Yosemite Lake Smith Canal sediment that was investigated in this pilot study.

However, there is controversy about the adequacy of a 1 mg/kg PCB sediment cleanup objective. A preliminary review of the Upper Fox River, Wisconsin, PCB sediment contamination problem shows that environmental groups and others (http://www.foxriverwatch.com) have stated that the 1 mg/kg cleanup objective will not prevent excessive bioaccumulation of PCBs. This will be an important issue to investigate in the further studies of this problem in Smith Canal. If the single sample of Yosemite Lake sediments is representative, then there is, apparently, significant bioaccumulation of PCBs from these sediments into white catfish, largemouth bass, other fish and likely fish-eating birds.

While the PCB sediment cleanup program on the Hudson River in New York state is said to also use a 1 mg/kg cleanup value, Tomchuk (pers. comm.,2002), US EPA Project Manager for the Hudson River PCBs Superfund Site, has indicated that the cleanup objective for the Hudson River PCBs was 3 g/m^2 in River Section 1, and 10 g/m^2 in River Section 2 and in selected areas of River Section 3. The 1 mg/kg residual expected to be reached after dredging (in areas where dredging occurs) is based on the ability of typical dredging equipment and the underlying substrate (which should allow for overcutting in most areas). Further information on the PCB cleanup in the Hudson River is available at http://www.epa.gov/hudson.

One of the objectives of the additional studies would be to establish the biota sediment accumulation factor for Smith Canal Yosemite Lake sediments sampled and the dominant types of edible fish taken from Yosemite Lake and Upper Smith Canal. Consideration will need to be given to the lipid content of the fish, as well as their length, in establishing this factor. This factor will be potentially useful as a first-cut approximation to the necessary sediment cleanup objective. As discussed, this biota sediment accumulation factor is an approximation that will likely need to be refined as sediment remediation takes place.

Managing the OCl Bioaccumulation Problem in the Central Valley of California

The OCl Bioaccumulation Problem

The Delta, and the Sacramento and San Joaquin Rivers and many of their tributaries have been found to contain fish whose edible tissues contain concentrations of organochlorine pesticides and/or PCBs at levels that are considered by the US EPA and the Office of Environmental Health Hazard Assessment (OEHHA) to be hazardous to the health of those who consume the fish (WRCB/TSM, 2001; MacCoy and Domagalski 1999; Davis 2000; Davis *et al*. 2000; SRWP, 2000, 2001). What are deemed to be excessive concentrations of OCls in edible fish tissue are defined by the US EPA (1997) and OEHHA (1999) based on an increased cancer risk associated with the consumption of a certain amount of the OCl-containing fish over the person's lifetime.

While the focus of this review is bioaccumulation of OCls in edible fish tissue that threatens the health of those people who eat the fish, this issue is also important for the protection of aquatic and terrestrial wildlife. Not only are the aquatic organisms at risk of adverse impact of the bioaccumulated OCls, but also, higher trophic level wildlife that use those fish and other aquatic life as food could be adversely impacted. Jarvinen and Ankley (1999) have published an review, "Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals," that provides information on impacts of chemical tissue residues on the health of the host organism.

Briuer (2002) has proposed to use the toxic effects of benthic organism tissue residues to inexpensively screen for excessive bioaccumulation. According to Briuer, this approach, if successful, would greatly reduce the cost of bioaccumulation testing of sediments by reducing the amount of chemical analyses needed in this testing.

It is well-known that GC/GCMS scans of some fish tissue OCl extracts contain a number of unknown chemicals (peaks) that are potentially hazardous. Therefore, the development of OCl management programs to control excessive bioaccumulation of OCls in fish tissue is in the direction of also controlling the adverse impacts of non-regulated bioaccumulatable chemicals that are a threat to the host organism, higher trophic level organisms and humans.

OCls of Concern. The organochlorine pesticides of concern include DDT, aldrin, dieldrin, chlordane, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane (including lindane), endosulfan and toxaphene. These chemicals were banned from further use many years ago because of their persistence in terrestrial and aquatic environments and their potential adverse effects to humans and terrestrial wildlife. They are called "legacy" pesticides because they have left a legacy of residues in areas where they were used. Aquatic sediments in some areas that received runoff from areas of application have accumulated sufficient concentrations of available forms of these OCls to cause resident fish to bioaccumulate excessive concentrations (based on a human health threat to cause cancer), threatening the health of those who use the fish as food. While not pesticides but rather industrial chemicals,

polychlorinated biphenyls (PCBs), are also highly persistent OCls in the environment. Like the legacy OCl pesticides, they are frequently found to have bioaccumulated to excessive levels in fish in areas where they have accumulated in aquatic sediments, again posing a cancer risk to those who consume the fish.

Waterbodies of Concern. The excessive bioaccumulation of OCls in edible fish within the Sacramento-San Joaquin River Delta and its tributaries has caused some of these waterbodies to be listed as Clean Water Act (CWA) 303(d) "impaired" waterbodies (Table 3). In addition to the 1998 303(d) listed waterbodies for excessive OCls in fish tissue shown in Table 3, there are other waterbodies in the Delta and its tributaries that have also been found to contain excessive concentrations of some OCls, such as the mainstem of the Sacramento River and a number of the tributaries of the San Joaquin River. These waterbodies could be listed in the next round of 303(d) "impaired" waterbodies because of excessive bioaccumulation of OCls.

Table 3

CVRWQCB/SRWB 1998 303(d) Listed Waterbodies for OCl Pesticides and PCBs

American River, Lower	Group A Pesticides
Colusa Drain	Group A Pesticides
Delta Waterways	Group A Pesticides, DDT
Feather River, Lower	Group A Pesticides
Kings River, Lower	Toxaphene
Merced River, Lower	Group A Pesticides
Natomas Main Drain	PCBs
San Joaquin River	Group A Pesticides, DDT
Stanislaus River, Lower	Group A Pesticides
Tuolumne River, Lower	Group A Pesticides
Stockton Deep Water Ship Channel	Dioxins, Furans, PCBs

Additional Waterbodies That Have Been Found to Contain Organochlorines in Fish Tissue above Critical Levels

Sacramento River	Group A Pesticides, DDT and PCBs
Smith Canal (City of Stockton)	PCBs

Group A Pesticides

aldrin, dieldrin, chlordane, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane (including lindane), endosulfan, and toxaphene.

The 303(d) listing of waterbodies is based primarily on the SWRCB Toxic Substances Monitoring (TSM) Program data. The TSM and 303(d) information are available from the WRCB website (see references). The CVRWQCB/SWRCB is currently reviewing the 303(d) listing of waterbodies for excessive bioaccumulation of OCls and could be adding to or removing waterbodies from the 1998 listing.

Dr. J. Davis of the San Francisco Estuary Institute (SFEI), as well as J. Karkoski and J. Bruns of the CVRWQCB, have contributed updated information which has been included in Table 3.

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Further, based on USGS studies (Brown, 1998) of the San Joaquin River watershed, some westside tributary streams have been found to contain concentrations of OCl pesticides that are well-above those that have been found to bioaccumulate to excessive levels in edible fish tissue. It is possible that studies of the fish taken from these streams would show that they should also be considered CWA 303(d) "impaired." Dr. J. Domagalski has indicated (pers. comm., 2001), based on USGS studies, that elevated concentrations of some OCl pesticides are frequently found in Orestimba Creek and probably Del Puerto Creek, Spanish Grant Drain and Ingram Hospital Creek.

Dioxins and Furans. A group of persistent, bioaccumulatable OCls that has not been adequately investigated in the Delta and its tributaries is the dioxins and furans. The dioxins and furans are formed in certain chemical manufacturing processes; they are also products of combustion. Excessive concentrations of these highly hazardous chemicals have been found in some Delta fish. In the early 1990s, fish taken from the Sacramento River below Anderson, CA, contained excessive concentrations of dioxins and furans. These OCls were discharged by the Simpson Paper Company at its Anderson mill. Simpson modified its paper-making processes to eliminate the discharge of dioxins and furans to the River. Within a few years after changing the paper manufacturing process, the concentrations of the dioxins and furans in the fish tissue decreased to acceptable levels. However, there is still a substantial legacy of dioxins and furans in sediments downstream of the reaches of the Sacramento River where excessive bioaccumulation of these chemicals in fish tissue used to occur.

Because of sediment scour that occurs under high-flow conditions, Sacramento River-derived sediment residues of dioxins and furans are likely to be present in the San Joaquin River Delta and possibly in San Francisco Bay. Excessive bioaccumulation of dioxins and furans has been found in some fish in the Delta and in San Francisco Bay (SFBRWQCB, 1997). However, inadequate attention has been given to the excessive bioaccumulation of dioxins and furans in the Sacramento-San Joaquin River Delta and its tributaries. These chemicals are being found in urban area street and highway stormwater runoff (Fisher, *et al*., 1999), and therefore would be also expected to be present in water and sediments near urban areas such as Sacramento and Stockton.

Overall Significance. The excessive bioaccumulation of OCls is one of the most important water quality management problems in the Sacramento-San Joaquin River Delta and its tributaries. This justifies focusing resources on developing a management program to control the excessive bioaccumulation of OCls in fish in the Delta and its tributaries. Until such a program is implemented, some of the aquatic life-related beneficial uses of the Delta and its tributaries will continue to be significantly impaired.

Development of a TMDL for Control of Excessive OCl Bioaccumulation. The current 303(d) listing requires that the Central Valley Regional Water Quality Control Board (CVRWQCB) develop total maximum daily loads (TMDLs) to control, to the extent possible, the sources of the OCls that are contributing to excessive bioaccumulation in edible fish tissue. Dr. G. Fred Lee is under contract with the State Water Resources Control Board to develop information to support a Technical TMDL to control excessive bioaccumulation of OCls in Central Valley fish. That contract covers the development of a Problem Statement, Discussion of Numeric Targets, Source Analyses, Linkage Analyses that could

lead to a TMDL Allocation, Implementation Plan, Monitoring and Evaluation, and Basin Plan Amendments.

Focus of the OCl Management Program. Sufficient work has already been done on the OCl management TMDL project to determine that there are several major information gaps on the concentrations of total and available (bioaccumulatable) OCl residues in sediments of selected areas of waterbodies within the Delta and its tributaries in which fish have been found to contain excessive amounts of OCls. There is also inadequate information on the specific agricultural and urban soil areas that are current sources of OCl pesticides potentially contributing to an ongoing accumulation of OCl pesticides in aquatic sediments that, in turn, is contributing to excessive bioaccumulation of OCls in edible fish tissue. Further, there is need for additional fish tissue OCl measurements to more fully define the current problem of excessive bioaccumulation of OCls in the Delta and its tributaries. There is need for studies specifically designed to develop an information base on current levels of bioaccumulatable OCl pesticides and PCBs in Delta waterbody sediment, potential current sources of OCls for these waterbodies, and the current concentrations of OCls in tissue of fish from certain insufficiently investigated waterbodies.

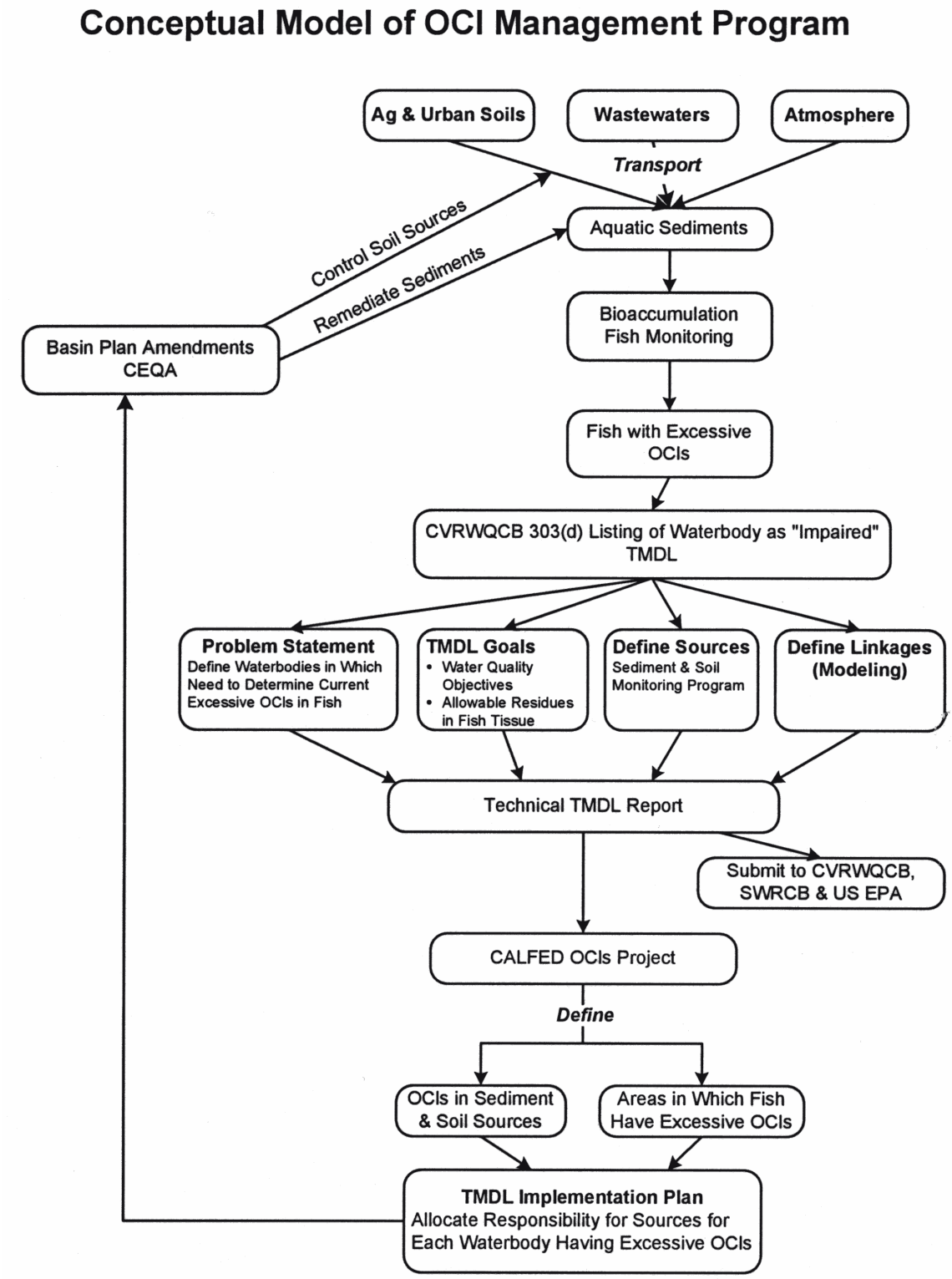
Conceptual Model for Management of Excessive Bioaccumulation of OCls. Figure 1 presents a conceptual model that describes the management of excessive bioaccumulation of OCls in Sacramento-San Joaquin River Delta and Delta tributary fish. The three modes of transport of the OCls (stormwater runoff from agricultural and urban soils, wastewater discharges from municipal and industrial sources, and the atmosphere) all contribute OCls to waterbodies where they become incorporated into the sediments. Through bioaccumulation processes, area fish acquire OCls from the sediments and/or from the benthic food chain; fish tissue monitoring has shown that edible tissues of some fish contain excessive concentrations of OCls. This has caused the CVRWQCB to define waterbodies with fish that have excessive levels of OCls as 303(d)-listed "impaired" waterbodies. This listing sets in motion the Technical TMDL process.

The Technical TMDL has four major components:

- The **problem statement** defines the waterbodies in which excessive concentrations of OCls have been found in fish tissue, or in which there is need to determine whether fish tissue contains excessive OCls. While the existing database on OCl concentrations in fish tissue is somewhat adequate to indicate whether or not there are excessive bioaccumulations of organochlorines, it does not define the extent nor magnitude of this problem. The TMDL problem statement should include a discussion of the monitoring program needed to better define the OCl excessive bioaccumulation problem in fish in the Delta and its tributaries.
- The **TMDL goal** is traditionally the water quality objective. However, because of the unreliability of water quality objectives in predicting bioaccumulation (except under worst-case conditions), increasing emphasis is being placed on using an acceptable fish tissue residue as the TMDL goal.
- **Defining the sources** of sediments and soils that are contributing OCls to waterbodies and their associated fish is the third major component of a Technical TMDL. A monitoring program will need to be established to define whether there are significant sources of terrestrial soils that

contribute bioaccumulatable organochlorine pesticides. Further, there is limited information on the amounts of organochlorine pesticides, PCBs, and dioxins in Central Valley sediments, which are the ultimate source of the OCls that bioaccumulate to excessive levels in fish.

Figure 1



- Defining the **linkage (modeling)** or relationship between the concentrations in water, soils and sediments, and the fish tissue residues. This relationship cannot be developed well at this time because of a lack of reliable information on the concentrations of OCls in stormwater runoff, irrigation tailwater, wastewater discharges, and the atmosphere. The technical TMDL will define the program needed to establish linkage between sediments/soil OCl residues and excessive fish tissue residues. It will likely incorporate the US EPA (2000a) biota sediment accumulation factor approach. It may also make use of the US EPA's BASS model of food web bioaccumulation discussed herein.

The four major components of the TMDL are integrated into a Technical TMDL, which is to be developed by the Central Valley Regional Water Quality Control Board, which is then submitted to the State Water Resources Control Board, and, ultimately, the US EPA.

From the information available, it is clear that a Technical TMDL devoted to the OCl excessive bioaccumulation problem will have major information gaps regarding terrestrial and aquatic sediment sources of OCls that have accumulated to excessive levels in certain Central Valley waterbody fish. For some waterbodies there is need to update the information on OCl levels in fish tissue. There is also need to expand the information base to include measurements from areas that have not been evaluated in the past, such as some of the westside tributaries of the San Joaquin River.

As shown in Figure 1, the conceptual model for the managing the excessive bioaccumulation of OCls has two major components. One is to define the sediment and soil sources of OCls that are leading to excessive OCl residues in tissue of fish from certain Central Valley waterbodies. The other is to define waterbodies with fish that have excessive OCl levels but that have not been adequately sampled thus far. Information developed from these two components should be provided to the TMDL Implementation Plan, wherein an allocation of the responsibility for the sources of OCls for each waterbody with excessive OCls in fish tissue is to be defined.

This TMDL Implementation Plan then becomes the basis for the CVRWQCB Basin Plan Amendments in which, through a California Environmental Quality Act (CEQA) process, a program is developed to control the excessive OCls. This program should be directed toward control of the soil sources of OCls that are continuing to contribute OCls that are accumulating in waterbody sediments and fish tissue. It should also focus on remediating OCl "hot spots" in sediments that have been shown to be potentially significant sources of OCls that are accumulating to excessive levels in fish.

The conceptual model shown in Figure 1 represents the first phase of the TMDL process. The waterbodies containing fish with excessive concentrations of OCls and undergoing remediation of sources and/or sediment, will then be monitored through the TMDL Phase I. This monitoring is to provide information to better define the linkage between the concentrations of OCls in water/sediments and the fish tissue residues. Because of the lack of definitive knowledge in this area, remediation will likely have to be undertaken in a number of steps to eventually control OCl bioaccumulation in fish tissue.

It is important to understand that the OCl pesticides and PCBs may not be derived from "hot spots" of OCls in sediments, but may be released from essentially all of the waterbody sediments. If the latter is the case, it may not be possible to fund remediation technologies either because it would be too expensive to control the runoff of OCl pesticides from agricultural and urban areas where they have previously been used, or because there is such a diffuse, general distribution of available OCl pesticides in waterbody sediments that sediment remediation is not economically feasible.

An important component of an OCl management program is to focus on assessing bioavailable forms of OCls in runoff from agricultural and urban areas through the use of US EPA standard methodology for measuring the ability of organisms to take up bioaccumulatable chemicals from sediments. It has been known for many years that the total concentrations of OCl pesticides, PCBs, or dioxins in sediments or soils is not a reliable measure of the bioavailable forms of those chemicals. This necessitates the use of organisms to determine whether measured OCl residues in sediments or soils are available for bio-uptake.

One of the primary factors controlling the bioavailability of OCls is the total organic carbon (TOC) content of the sediments. In the early 1990s, the US EPA thought that it could relate the bioavailability of certain organochlorine pesticides in sediments to the sediment organic carbon content, and thereby chemically measure directly the fraction of the OCls available for bioaccumulation. However, it has been established that the process of binding of OCl pesticides, PCBs, and dioxins is far more involved than just generic TOC binding.

During the 1970s, under contract with the Corps of Engineers, Dr. G. Fred Lee conducted studies of the release of organochlorine pesticides and PCBs from sediments from about 100 different US waterways. He found that PCBs were most readily released to the water column from sediment suspension when the sediments had a low petroleum hydrocarbon content. This release was not necessarily related to the TOC content of the sediments. Sediments with a low petroleum hydrocarbon content, which are typically sandy type sediments such as obtained several miles out in the Gulf of Mexico near Galveston, Texas, readily released a substantial portion of the PCBs present in the sediments. Sediments with high petroleum hydrocarbon content which had much higher concentrations of PCBs (taken from the Houston Ship Channel) released little of the PCBs upon suspension into the water column.

It is clear that equilibrium partitioning with TOC is not the only mechanism controlling PCB release. How this relates to bioaccumulation, which is the other important process governing the transfer of PCBs from sediments to aquatic organisms through the food web, is not well understood. This has been a long-standing issue that still has not been adequately addressed. It is of importance in determining the appropriate approach to take for sediment remediation for controlling OCl excessive bioaccumulation.

One of the possible products of the needed studies, which would help advance the science of managing excessive OCl bioaccumulation, is a better understanding of how OCls in sediments are bound to the sediments, and thereby are rendered unavailable for bio-uptake. An important aspect of

this study is the investigation of the OCls in sediment, water and fish, and the coupling between the OCls in sediments and water, in a variety of Central Valley waterbodies. This can lead to a better understanding of processes of controlling bio-uptake of OCls than would be gained by investigating one or two waterbodies. It is possible that certain patterns will evolve from the measurements of OCl concentrations in sediments and the OCl uptake by the test organisms, that could provide insight into the binding mechanisms. It should be possible to conduct certain laboratory experiments to aid in the fundamental understanding of OCl pesticide and PCB availability from sediments.

Overall, the conceptual model governing the management of excessive OCl bioaccumulation in edible fish is based on the hypothesis that in order to develop a control program for excessive bioaccumulation of organochlorine pesticides and PCBs in fish tissue within the Delta and its tributaries, it is necessary to better understand the specific sources of the bioaccumulated OCls to waterbodies in which the fish have excessive tissue concentrations, as well as the potential role of current land-derived inputs of OCls associated with stormwater runoff and irrigation tailwater.

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Appendix A

Toxicity and Bioaccumulation Evaluation of Sediments From Smith Canal (Stockton, CA)

(Samples Collected September 6, 2001)

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Toxicity and Bioaccumulation Evaluation of Sediments From Smith Canal (Stockton, CA)

(Samples Collected September 6, 2001)

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Toxicity and Bioaccumulation Evaluation of Sediments From Smith Canal (Stockton, CA)

1.0 INTRODUCTION

As part of a preliminary monitoring program, Dr. G. Fred Lee has contracted Pacific EcoRisk (PER) to perform toxicity and bioaccumulation evaluations of sediments collected from Smith Canal in Stockton, CA. These evaluations consist of performing the following US EPA tests:

- 10-day survival and growth sediment test with the amphipod *Hyalella azteca*;
- 28-day sediment bioaccumulation test with the oligochaete *Lumbriculus variegatus*.

This report describes the performance and results of these tests.

2.0 TEST PROCEDURES

The amphipod survival and growth test with *Hyalella* and the oligochaete bioaccumulation test with *Lumbriculus* were performed following the guidelines established in the US EPA manual "Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates" (EPA/600/R-99/064).

2.1 RECEIPT AND HANDLING OF SEDIMENT SAMPLES

On September 6, 2001, grab samples of Smith Canal project site sediments were collected at mid-channel at Yosemite Lake, about halfway between Yosemite Lake and the mouth of Smith Canal, and near the mouth of Smith Canal where it intersects with the San Joaquin River Deep Water Ship Channel opposite Rough and Ready Island. Samples were collected using appropriately-cleaned coated stainless steel Van Veen grab samples with a 0.1 m^2 sampling area. For each site, the top 2.5 cm of sediment from each grab was removed using a stainless steel spatula, and composited within a pre-cleaned HDPE bucket. These samples were placed "on ice" in ice-chest coolers and delivered that same day, under chain of custody, to the Pacific EcoRisk testing laboratory in Martinez, CA. (Chain of Custody documentation is available from Pacific EcoRisk or G. Fred Lee & Associates.) Upon receipt at the laboratory, the samples were stored within a walk-in refrigerator at 4°C until needed.

2.1.1 Determination of Sediment Porewater Characteristics

Prior to test initiation, bulk sediment from each sample site was removed from the sample refrigerator and re-homogenized. An aliquot of each sediment was then centrifuged at 2,500g for 30 minutes, after which the porewater supernatant was carefully poured off for determinations of porewater pH, salinity, total ammonia and sulfide (Table 1).

2.2 TEST ORGANISMS

The *Hyalella azteca* used in the sediment toxicity tests and the *Lumbriculus variegatus* used in the sediment bioaccumulation tests were obtained from a commercial supplier (Aquatic Biosystems, Ft. Collins, CO).

Table 1. "Smith Canal Project" sediment porewater quality characteristics.

Sample Station I.D.	pH	Salinity (ppt)	Total Ammonia (mg/L N)	Sulfide (mg/L)
Smith Canal: Mouth	7.5	0.1	1.64	0.04
Smith Canal: Mid-Channel	7.2	0.2	6.80	0.04
Yosemite Lake	7.0	0.2	16.1	0.06

2.3 TOXICITY TESTING

2.3.1 Solid-Phase Sediment Toxicity Testing with *Hyalella azteca*

The freshwater sediment toxicity test with *Hyalella azteca* consists of exposing the amphipods to the sediment for 10 days, after which effects on survival and growth are evaluated. The specific procedures used in this test are described below.

Each of the three site sediments were tested at the 100% concentration only. The Control treatment sediment consisted of the same reference soil which is used as the routine control sediment by the National Biological Survey (Columbia, MO) in their freshwater sediment toxicity tests. There were eight replicates for each of the test treatments. Each replicate container consisted of a 300 mL tall-form glass beaker with a 3 cm band of 540 µm mesh NITEX attached to the top of the beaker with silicone sealant. Each of the sediment samples was re-homogenized immediately prior to introduction of the sediments into the test replicates. Approximately 100 mL of sediment was loaded into each of the test replicate containers. Each of the test replicates was then carefully filled with clean overlying water (synthetic Moderately Hard water, modified for use with *Hyalella* as per the US EPA test guidelines). The replicates with sediments and clean overlying water were established 24 hrs prior to the introduction of the amphipods.

After this initial 24-hr period, the overlying water in each replicate was flushed with one volume of fresh control water (approximately 150 mL) using a modified Zumwalt delivery system (Zumwalt, *et al*., 1994). A small aliquot of the renewed overlying water in each of the eight replicates, per treatment, was then collected and composited for measurement of "initial" test water quality characteristics (pH, DO, conductivity, alkalinity, hardness, and total ammonia). Then ten 13-14 day-old amphipods were randomly allocated into each replicate, followed by the addition of 1.5 mL of YCT food. The test replicates were then returned to the water baths.

Each day, for the following nine days, the test replicates were pulled from the water bath, and each replicate was examined for the presence of any dead amphipods. A small aliquot of the overlying water

in each of the eight replicates was then collected and composited as before for measurement of "old" DO, after which each replicate was flushed with one volume of fresh water. Another small aliquot of the overlying water in each of the eight replicates was then collected and composited as before for measurement of "new" DO, after which each replicate was fed 1.5 mL of YCT, and then replaced within the water bath.

After 10 days exposure, the replicate containers were pulled from the water bath, and an aliquot of overlying water was collected from each replicate and composited for analysis of the "final" water quality characteristics. The sediments in each replicate container were then carefully washed out and sieved using a No. 40 (425 µm mesh) stainless steel sieve, and the number of surviving amphipods determined. The surviving amphipods from each replicate were then euthanized in methanol, rinsed with de-ionized water, and transferred to a pre-dried and pre-tared drying pan. These were then dried at 100°C for 24 hrs and re-weighed to determine the mean weight per individual *Hyalella*. The data for each sediment treatment were analyzed and compared to the Control treatment to determine whether or not any statistically significant differences were observed. All statistical analyses were performed using the ToxCalc statistical package (Version 5.0, TidePool Scientific, McKinleyville, CA).

2.3.2 Reference Toxicant Testing of the *Hyalella*

In order to document that the organisms in these tests were responding to toxic stress in a typical fashion, a concurrent reference toxicant test (with potassium chloride, KCl) was performed. The test conditions for the reference toxicant test followed the guidelines established in the US EPA manual "Methods for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates" (EPA/600/R-99/064). The reference toxicant test for *Hyalella azteca* consists of a 96-hr static exposure to KCl at test concentrations of 0.1, 0.2, 0.3, 0.4, and 0.5 g/L. After 96 hrs exposure, the number of surviving amphipods in each replicate were determined. The resulting survival data were statistically analyzed, using the ToxCalc statistical package, to determine the EC50 point estimates.

The results of this test were compared to the database of previously-performed reference toxicant tests: the EC50 value fell within the acceptable range (mean $\pm$ 2 S.D.), indicating that these test organisms were responding to chemical stress in a typical fashion.

2.4 SEDIMENT BIOACCUMULATION TESTING

The freshwater sediment bioaccumulation test with *Lumbriculus variegatus* consists of exposing the oligochaetes to the sediment for 28 days, after which the worms are removed from the sediment, cleaned, and then sent to the analytical laboratory. The specific procedures used in this test are described below.

Approximately 24 hrs prior to the initiation of these tests, the sediment samples for each site were removed from the sample refrigerator, allowed to come to room temperature, and were then re-homogenized. Large debris (roots, twigs, etc.) were removed from each sample at this time. Each of

the site sediments was tested at the 100% concentration only. The Control treatment consisted of a water-only exposure.

Approximately 4 L of the homogenized bulk sediment from each site were randomly allocated into each of five labeled replicate containers, each consisting of a pre-cleaned 8 L HDPE tub. Each replicate was then carefully filled with 2 L of US EPA synthetic moderately hard water. The Control treatment replicates consisted of the same 8 L HDPE tubs containing 6 L of water only (the Control treatment *Lumbriculus* were fed dried-and-pressed *Spirulina, ad libitum,* during the test exposures). The test replicates were then placed into a temperature-controlled water bath at 23°C under cool-white fluorescent lighting on a 16L:8D photoperiod. Approximately 24 hrs later, a small aliquot of the overlying water in each of the appropriate replicates was collected and composited for measurement of "pre-test" water quality characteristics (pH, DO, conductivity, alkalinity, hardness, and total ammonia). Each replicate was then flushed with one volume of fresh overlying water. Due to observation of low DO levels in some of the test treatments, each replicate was gently aerated throughout the test exposure duration.

Upon observation that all test replicate overlying water DO concentrations had increased to > 60% saturation, the tests were initiated by the random allocation of five g of adult *Lumbriculus* (as per US EPA guidelines, in order to account for the weight of interstitial water present in each batch of worms, the target loading biomass was multiplied by 1.33, such that the wet weight of the *Lumbriculus* loaded into each test replicate was weighed out at approximately 6.66 g). At the time of test initiation, five replicates containing approximately five g of *Lumbriculus* tissue were collected and frozen for analysis of T_0 contaminant concentrations. This is the concentration that is present in the worms at the start of the test prior to exposure to the test sediments.

Each day, the "old" DO concentration was measured for the overlying water in one randomly selected test replicate per treatment replicate set, after which the overlying water in each replicate was replaced with fresh water.

After 28 days of test exposure, aliquots of the overlying water for each set of test replicates being terminated were collected and composited for determination of "final" water quality characteristics (pH, DO, conductivity, alkalinity, hardness, and total ammonia). Then, the contents of each replicate container were carefully washed through a series of HDPE sieves, with retained material being transferred to glass dishes placed atop light boxes for final collection of the individual *Lumbriculus*. The *Lumbriculus* collected from each replicate were carefully cleaned via pipette to remove extraneous sediment and detritus, and were then maintained in small HDPE containers containing clean Control water for a 24-hr depuration period. After the depuration period, the cleaned *Lumbriculus* were transferred into pre-cleaned and pre-weighed 60 mL glass sample jars with teflon-lined lids. The interstitial water was carefully removed by blotting the tissue mass with Kim-Wipe laboratory wipes, after which the sample jar was re-weighed to determine the final *Lumbriculus* biomass for each replicate. The sample jars, containing the *Lumbriculus* biomass, were then placed in a freezer, where they were held until packaged for transportation to the analytical laboratory.

3.0 RESULTS

The results of the toxicity evaluations of the Smith Canal Project sediments are presented below.

3.1 SEDIMENT TOXICITY TESTING RESULTS

3.1.1 Toxicity of Smith Canal: Mouth Sediments to *Hyalella azteca*

The survival and the growth results of the test of "Smith Canal: Mouth" sediments are summarized in Table 2. Briefly, there was 88.75% survival of the amphipods at the Control treatment. There was a mean of 95% survival of the *Hyalella* in the "Smith Canal: Mouth" sediment, which was not significantly less than the Control. Analysis of the growth data indicated a mean amphipod weight of 0.17 mg for the Control treatment. The mean *Hyalella* weight for the "Smith Canal: Mouth" sediment was 0.22 mg, which was not significantly less than the Control.

The test data & summary of statistical analyses for this test are available from Pacific EcoRisk.

Table 2. Toxicity of "Smith Canal: Mouth" Sediment to *Hyalella azteca* survival and growth.

	Rep A	Rep B	Rep C	Rep D	Rep E	Rep F	Rep G	Rep H	Mean
	% Survival								
Control	80	100	90	90	90	90	80	90	88.75
Smith Canal: Mouth	100	90	100	100	90	90	90	100	95
	Mean Amphipod Dry Weight (mg)								
Control	0.20	0.14	0.13	0.11	0.25	0.26	0.12	0.12	0.17
Smith Canal: Mouth	0.27	0.21	0.18	0.17	0.29	0.25	0.20	0.19	0.22

3.1.2 Toxicity of Smith Canal: Mid-Channel Sediments to *Hyalella azteca*

The survival and the growth results of the test of "Smith Canal: Mid-Channel" sediments are summarized in Table 3.

Table 3. Toxicity of "Smith Canal: Mid-Channel" Sediment to *Hyalella* survival and growth.

	Rep A	Rep B	Rep C	Rep D	Rep E	Rep F	Rep G	Rep H	Mean
	% Survival								
Control	80	100	90	90	90	90	80	90	88.75
Smith Canal: Mid-Channel	100	90	90	90	80	100	90	90	91.25
	Mean Amphipod Dry Weight (mg)								
Control	0.20	0.14	0.13	0.11	0.25	0.26	0.12	0.12	0.17
Smith Canal: Mid-Channel	0.18	0.15	0.17	0.15	0.24	0.14	0.15	0.12	0.16

Briefly, there was 88.75% survival of the amphipods at the Control treatment. There was a mean of 91.25% survival of the *Hyalella* in the "Smith Canal: Mid-Channel" sediment, which was not significantly less than the Control. Analysis of the growth data indicated a mean amphipod weight of 0.17 mg for the Control treatment. The mean *Hyalella* weight for the "Smith Canal: Mid-Channel" sediment was 0.16 mg, which was not significantly less than the Control.

The test data & summary of statistical analyses for this test are available from Pacific EcoRisk.

3.1.3 Toxicity of Yosemite Lake Sediments to *Hyalella azteca*

The survival and the growth results of the test of Yosemite Lake sediments are summarized in Table 4. Briefly, there was 88.75% survival of the amphipods at the Control treatment. *Hyalella* survival was reduced to 62.5% in Yosemite Lake, which was significantly less than the Control. Analysis of the growth data indicated a mean amphipod weight of 0.17 mg for the Control treatment. The mean *Hyalella* weight for the Yosemite Lake sediment was 0.14 mg, which was not significantly less than the Control.

The test data & summary of statistical analyses for this test are available from Pacific EcoRisk.

Table 4. Toxicity of "Yosemite Lake" Sediment to *Hyalella azteca* survival and growth.

	Rep A	Rep B	Rep C	Rep D	Rep E	Rep F	Rep G	Rep H	Mean
	% Survival								
Control	80	100	90	90	90	90	80	90	88.75
Yosemite L.	70	50	60	70	60	60	70	60	**62.5 ***
	Mean Amphipod Dry Weight (mg)								
Control	0.20	0.14	0.13	0.11	0.25	0.26	0.12	0.12	0.17
Yosemite L.	0.17	0.15	0.14	0.12	0.16	0.18	0.10	0.10	0.14

* - Significantly less than the Control treatment response at $p < 0.05$.

3.1.4 Reference Toxicant Toxicity to *Hyalella azteca*

The results of the reference toxicant evaluation of the response of these test organisms to toxic stress are summarized in Table 5a. There was 100% amphipod survival at the Control treatment, and not less than 80% survival at any of the potassium chloride treatments up through the 0.3 g/L treatment, none of which were significantly less than the Control. At the 0.4 g/L treatment, *Hyalella azteca* survival was reduced to 50% which was significantly less than the Control. The EC50 was 0.35 g/L. The test data & summary of statistical analysis for this test are available from Pacific EcoRisk.

The results of reference toxicant tests performed previously in this lab are summarized in Table 5b. The response of the test organisms used in the current tests was consistent with previous test results (i.e., within the range established by the mean $\pm$ 2 S.D.), indicating that these test organisms were responding to toxic stress in a typical fashion.

Table 5a. Reference toxicant testing: Effects of KCl on *Hyalella azteca* survival.	
KCl Treatment (g/L)	% Survival
Control	100
0.1	90
0.2	100
0.3	80
0.4	50 *
0.5	0 *
EC50 = 0.35 g/L	

* Significantly less than the Control treatment at $p < 0.05$.

Table 5b. *Hyalella azteca* Reference Toxicant Testing: Comparison with Previous Test Database	
Test Project Number	EC50 (g/L KCl)
546	0.4
868	0.4
1872	0.48
2995	0.37
3071	0.30
3078	0.36
3373	0.35
Acceptable range (mean $\pm$ 2S.D.)	0.38 + 2(0.06) = 0.27-0.49

3.2 RESULTS OF SEDIMENT CHEMICAL ANALYSIS

Three sediment samples were sent to the Department of Fish and Game (DFG) Fish and Wildlife Water Pollution Control Laboratory. The samples were extracted by DFG using pressurized fluid extraction (Dionex ASE 200) with acetone/dichloromethane (50:50). Gel permeation chromatography was used to remove sulfur from sample extracts. Sample extracts were fractionated using Florisil column chromatography and analyzed for organochlorine pesticides and PCBs using dual capillary column gas chromatography with electron capture detection.

3.2.1 Sediment TOC Analysis

The total organic carbon (TOC) content of the three Smith Canal sediment samples are presented in Table 6.

Table 6. Smith Canal Sediment Total Organic Carbon	
Location	TOC (%)
Yosemite Lake	5.8
Smith Canal-Mid	3.5
Smith Canal-Mouth	0.5

These data show that Yosemite Lake, which is the upstream terminus of Smith Canal, and into which a large number of city storm sewers discharge, has a TOC of about 5.8 %, while Smith Canal-Mid has a TOC of 3.5 %, and the mouth of Smith Canal near where it discharges to the San Joaquin River Deep Water Ship Channel has a TOC of 0.5 %. These values are in accord with what would be expected, with the sediments near the mouth being sandy in character with a low TOC. Mid-Canal was somewhat grainy, but with more fines, and Yosemite Lake mostly fines. It would be expected that the highest PCBs and organochlorine pesticides would be associated with the Yosemite Lake sample because of the higher TOC content, particularly if the source of the PCBs was discharges (historical and/or current) into the lake.

3.2.2 PCB Congeners, PCB Aroclors and Organochlorine Pesticides in Smith Canal Sediments

The results of the analysis of the PCB congeners, PCB Aroclors and organochlorine pesticides in Smith Canal sediments are presented in Tables 7 through 14. The data for both fresh (wet weight) and dry weight are presented in these tables. In the discussion below, dry weight has been used.

The sample of Smith Canal sediment taken from Yosemite Lake (Table 11) was found to contain about 333 ng/g of PCB Aroclor 1254, and 816 ng/g of PCB Aroclor 1260. The concentration of Aroclor 1248 was less than the reporting limit, which was 86.2 ng/g. The duplicate analysis of the Yosemite Lake sample (Table 12) showed PCB Aroclor 1254 at 395 ng/g and PCB Aroclor 1260 at 953 ng/g. The duplicate analyses RPDs (relative percent differences) were 17% and 16% for the two Aroclors, respectively.

Congener analysis of the Yosemite Lake sediments (Table 7) indicated that the PCB congener numbers 95, 101, 110, 138, 141, 149, 151, 153, 170, 174, 177, 180, 183, 187, 194 and 201 were elevated compared to the other congeners in the Yosemite Lake sediment sample. These congeners had concentrations greater than about 18 ng/g. The sum of the PCB congeners for the Yosemite Lake sediment sample was 957 ng/g. The duplicate analysis of this sample had a sum of PCB congeners of 1120 ng/g, with a RPD of 16%. The sum of the Aroclors for the Yosemite Lake sediment sample was 1149 ng/g, and for the duplicate sample was 1348 ng/g, with a RPD of 16%. The sum of the congeners is in good agreement with the sum of the Aroclors.

The concentration of Aroclor 1248 in the Smith-Canal-Mid sediment sample (Table 13) was less than the reporting limit of 69.4 ng/g, while Aroclor 1254 was present at 182 ng/g, and Aroclors 1260 at 290 ng/g. Near the mouth of Smith Canal, the concentrations of all three PCBs were less than the reporting limits, which for Aroclors 1248, 1254 and 1260 were 35.7 ng/g, 14.3 ng/g and 14.3 ng/g, respectively. These results are in accord with what would be expected based on the TOC and the likely proximity of the source of PCBs – i.e., storm drains that discharge to Yosemite Lake – as well as the dilution of the sediments through mixing with the San Joaquin River sediments, which would be expected to contain lower PCBs.

Table 7

PCB Congeners – Yosemite Lake Sediments

PCB Congener No.	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	Yosemite Lake ppb (ng/g) Dry Weight	Yosemite Lake ppb (ng/g) Fresh Weight
8	0.2	0.690	ND	ND
18	0.2	0.690	<RL	<RL
27	0.2	0.690	<RL	<RL
28	0.2	0.690	**1.65**	**0.465**
29	0.2	0.690	ND	ND
31	0.2	0.690	**1.13**	**0.319**
33	0.2	0.690	<RL	<RL
44	0.2	0.690	**2.16**	**0.609**
49	0.2	0.690	**5.58**	**1.57**
52	0.2	0.690	**8.19**	**2.31**
56	0.2	0.690	**0.731**	**0.206**
60	0.2	0.690	<RL	<RL
66	0.2	0.690	**3.26**	**0.919**
70	0.2	0.690	**3.07**	**0.866**
74	0.2	0.690	**1.90**	**0.536**
87	0.2	0.690	**4.82**	**1.36**
95	0.2	0.690	**18.2**	**5.13**
97	0.2	0.690	**2.46**	**0.694**
99	0.2	0.690	**10.1**	**2.85**
101	0.2	0.690	**29.5**	**8.32**
105	0.2	0.690	**1.71**	**0.482**
110	0.2	0.690	**23.3**	**6.57**
114	0.2	0.690	**0.985**	**0.278**
118	0.2	0.690	**9.41**	**2.65**
128	0.2	0.690	**6.59**	**1.86**
137	0.2	0.690	<RL	<RL
138	0.2	0.690	**115**	**32.4**
141	0.2	0.690	**23.6**	**6.66**
149	0.2	0.690	**89.2**	**25.2**
151	0.2	0.690	**31.0**	**8.74**
153	0.2	0.690	**116**	**32.7**
156	0.2	0.690	**4.90**	**1.38**
157	0.2	0.690	**1.79**	**0.505**
158	0.2	0.690	**6.98**	**1.97**
170	0.2	0.690	**53.1**	**15.0**
174	0.2	0.690	**54.4**	**15.3**
177	0.2	0.690	**32.7**	**9.22**
180	0.2	0.690	**130**	**36.7**
183	0.2	0.690	**24.8**	**6.99**
187	0.2	0.690	**60.4**	**17.0**
189	0.2	0.690	**1.72**	**0.485**
194	0.2	0.690	**24.1**	**6.80**
195	0.2	0.690	**10.2**	**2.88**
200	0.2	0.690	**2.66**	**0.750**
201	0.2	0.690	**21.3**	**6.01**
203	0.2	0.690	**14.2**	**4.00**
206	0.2	0.690	**4.01**	**1.13**
209	0.2	0.690	<RL	<RL

Surrogate	**% Recovery**	**Dry Wt. Dec. Fraction**
207	**90.3**	**0.282**

***Dry Weight Reporting Limit based on the individual dry sample weight (2.90g).**

Table 8
PCB Congeners – Yosemite Lake Sediment Duplicate

PCB Congener No.	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	Yosemite Lake Dup. ppb (ng/g) Dry Weight	Yosemite Lake Dup. ppb (ng/g) Fresh Weight
8	0.2	0.678	ND	ND
18	0.2	0.678	<RL	<RL
27	0.2	0.678	ND	ND
28	0.2	0.678	**1.98**	**0.556**
29	0.2	0.678	ND	ND
31	0.2	0.678	**1.40**	**0.393**
33	0.2	0.678	<RL	<RL
44	0.2	0.678	**2.41**	**0.677**
49	0.2	0.678	**7.82**	**2.20**
52	0.2	0.678	**9.14**	**2.57**
56	0.2	0.678	<RL	<RL
60	0.2	0.678	<RL	<RL
66	0.2	0.678	**4.08**	**1.15**
70	0.2	0.678	**3.75**	**1.05**
74	0.2	0.678	**2.15**	**0.604**
87	0.2	0.678	**5.41**	**1.52**
95	0.2	0.678	**21.0**	**5.90**
97	0.2	0.678	**2.69**	**0.756**
99	0.2	0.678	**11.7**	**3.29**
101	0.2	0.678	**33.2**	**9.33**
105	0.2	0.678	**1.92**	**0.540**
110	0.2	0.678	**26.6**	**7.47**
114	0.2	0.678	**1.14**	**0.320**
118	0.2	0.678	**11.8**	**3.32**
128	0.2	0.678	**7.34**	**2.06**
137	0.2	0.678	**0.843**	**0.237**
138	0.2	0.678	**137**	**38.5**
141	0.2	0.678	**27.6**	**7.76**
149	0.2	0.678	**105**	**29.5**
151	0.2	0.678	**35.4**	**9.95**
153	0.2	0.678	**138**	**38.8**
156	0.2	0.678	**4.47**	**1.26**
157	0.2	0.678	**1.78**	**0.500**
158	0.2	0.678	**7.79**	**2.19**
170	0.2	0.678	**62.9**	**17.7**
174	0.2	0.678	**63.6**	**17.9**
177	0.2	0.678	**38.0**	**10.7**
180	0.2	0.678	**153**	**43.0**
183	0.2	0.678	**27.4**	**7.70**
187	0.2	0.678	**70.3**	**19.8**
189	0.2	0.678	**1.99**	**0.559**
194	0.2	0.678	**28.5**	**8.01**
195	0.2	0.678	**11.9**	**3.34**
200	0.2	0.678	**3.03**	**0.851**
201	0.2	0.678	**24.7**	**6.94**
203	0.2	0.678	**16.6**	**4.66**
206	0.2	0.678	**4.56**	**1.28**
209	0.2	0.678	<RL	<RL

Surrogate	**% Recovery**	**Dry Wt. Dec. Fraction**
207	**86.4**	**0.281**

***Dry Weight Reporting Limit based on the individual dry sample weight (2.95g).**

Table 9

PCB Congeners – Smith Canal: Mid Sediment

PCB Congener No.	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	Smith Canal Mid ppb (ng/g) Dry Weight	Smith Canal Mid ppb (ng/g) Fresh Weight
8	0.2	0.556	ND	ND
18	0.2	0.556	<RL	<RL
27	0.2	0.556	ND	ND
28	0.2	0.556	**1.36**	**0.484**
29	0.2	0.556	ND	ND
31	0.2	0.556	**0.934**	**0.333**
33	0.2	0.556	**1.93**	**0.687**
44	0.2	0.556	**2.29**	**0.815**
49	0.2	0.556	**2.44**	**0.869**
52	0.2	0.556	**4.76**	**1.69**
56	0.2	0.556	<RL	<RL
60	0.2	0.556	<RL	<RL
66	0.2	0.556	**2.13**	**0.758**
70	0.2	0.556	**2.76**	**0.983**
74	0.2	0.556	**0.945**	**0.336**
87	0.2	0.556	**3.75**	**1.34**
95	0.2	0.556	**10.1**	**3.60**
97	0.2	0.556	**2.25**	**0.801**
99	0.2	0.556	**5.25**	**1.87**
101	0.2	0.556	**15.3**	**5.45**
105	0.2	0.556	**2.10**	**0.748**
110	0.2	0.556	**14.1**	**5.02**
114	0.2	0.556	ND	ND
118	0.2	0.556	**7.54**	**2.68**
128	0.2	0.556	**3.42**	**1.22**
137	0.2	0.556	<RL	<RL
138	0.2	0.556	**45.6**	**16.2**
141	0.2	0.556	**8.07**	**2.87**
149	0.2	0.556	**33.2**	**11.8**
151	0.2	0.556	**11.8**	**4.20**
153	0.2	0.556	**43.3**	**15.4**
156	0.2	0.556	**1.99**	**0.708**
157	0.2	0.556	**0.776**	**0.276**
158	0.2	0.556	**3.06**	**1.09**
170	0.2	0.556	**17.9**	**6.37**
174	0.2	0.556	**18.1**	**6.44**
177	0.2	0.556	**11.5**	**4.09**
180	0.2	0.556	**43.3**	**15.4**
183	0.2	0.556	**8.53**	**3.04**
187	0.2	0.556	**20.0**	**7.12**
189	0.2	0.556	**0.605**	**0.215**
194	0.2	0.556	**8.19**	**2.92**
195	0.2	0.556	**3.60**	**1.28**
200	0.2	0.556	**0.927**	**0.330**
201	0.2	0.556	**7.95**	**2.83**
203	0.2	0.556	**5.21**	**1.85**
206	0.2	0.556	**1.72**	**0.612**
209	0.2	0.556	<RL	<RL

Surrogate	**% Recovery**	**Dry Wt. Dec. Fraction**
207	**87.9**	**0.356**

***Dry Weight Reporting Limit based on the individual dry sample weight (3.60g).**

Table 10
PCB Congeners – Smith Canal: Mouth Sediment

PCB Congener No.	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	**Smith Canal-Mouth ppb (ng/g) Dry Weight**	**Smith Canal-Mouth ppb (ng/g) Fresh Weight**
8	0.2	0.286	ND	ND
18	0.2	0.286	ND	ND
27	0.2	0.286	ND	ND
28	0.2	0.286	<RL	<RL
29	0.2	0.286	ND	ND
31	0.2	0.286	<RL	<RL
33	0.2	0.286	<RL	<RL
44	0.2	0.286	<RL	<RL
49	0.2	0.286	<RL	<RL
52	0.2	0.286	**0.338**	**0.220**
56	0.2	0.286	<RL	<RL
60	0.2	0.286	ND	ND
66	0.2	0.286	<RL	<RL
70	0.2	0.286	**0.358**	**0.233**
74	0.2	0.286	<RL	<RL
87	0.2	0.286	**0.300**	**0.196**
95	0.2	0.286	**0.473**	**0.308**
97	0.2	0.286	<RL	<RL
99	0.2	0.286	<RL	<RL
101	0.2	0.286	**0.797**	**0.520**
105	0.2	0.286	<RL	<RL
110	0.2	0.286	**0.772**	**0.503**
114	0.2	0.286	ND	ND
118	0.2	0.286	**0.530**	**0.346**
128	0.2	0.286	<RL	<RL
137	0.2	0.286	ND	ND
138	0.2	0.286	**1.66**	**1.08**
141	0.2	0.286	**0.294**	**0.192**
149	0.2	0.286	**1.18**	**0.769**
151	0.2	0.286	**0.376**	**0.245**
153	0.2	0.286	**1.49**	**0.971**
156	0.2	0.286	<RL	<RL
157	0.2	0.286	ND	ND
158	0.2	0.286	<RL	<RL
170	0.2	0.286	**0.524**	**0.342**
174	0.2	0.286	**0.543**	**0.354**
177	0.2	0.286	**0.292**	**0.190**
180	0.2	0.286	**1.17**	**0.763**
183	0.2	0.286	**0.308**	**0.201**
187	0.2	0.286	**0.641**	**0.418**
189	0.2	0.286	ND	ND
194	0.2	0.286	<RL	<RL
195	0.2	0.286	<RL	<RL
200	0.2	0.286	ND	ND
201	0.2	0.286	<RL	<RL
203	0.2	0.286	<RL	<RL
206	0.2	0.286	ND	ND
209	0.2	0.286	ND	ND

Surrogate	**% Recovery**	**Dry Wt. Dec. Fraction**
207	**88.6**	**0.652**

***Dry Weight Reporting Limit based on the individual dry sample weight (7.00g).**

Table 11

Pesticides and Aroclors – Yosemite Lake Sediment

	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	**Yosemite Lake ppb (ng/g) Dry Weight**	**Yosemite Lake ppb (ng/g) Fresh Weight**
aldrin	1.0	3.4	<RL	<RL
chlordane, cis	2.0	6.9	**27.5**	**7.76**
chlordane, trans	2.0	6.9	**30.5**	**8.60**
chlordene, alpha	1.0	3.4	**4.48**	**1.26**
chlordene, gamma	1.0	3.4	<RL	<RL
chlorpyrifos	2.0	6.9	<RL	<RL
dacthal	2.0	6.9	ND	ND
DCBP, p,p'	10.0	34.5	ND	ND
DDD, o,p'	2.0	6.9	**35.6**	**10.0**
DDD, p,p'	2.0	6.9	**214**	**60.3**
DDE, o,p'	2.0	6.9	**7.68**	**2.17**
DDE, p,p'	2.0	6.9	**130**	**36.7**
DDMU, p,p'	3.0	10.3	**15.5**	**4.37**
DDT, o,p'	3.0	10.3	<RL	<RL
DDT, p,p'	5.0	17.2	**19.9**	**5.61**
diazinon	20.0	69.0	<RL	<RL
dieldrin	2.0	6.9	<RL	<RL
endosulfan I	2.0	6.9	ND	ND
endosulfan II	10.0	34.5	<RL	<RL
endosulfan sulfate	10.0	34.5	**UJ**	**UJ**
endrin	2.0	6.9	<RL	<RL
ethion	6.0	20.7	**UJ**	**UJ**
HCH, alpha	1.0	3.4	ND	ND
HCH, beta	2.0	6.9	ND	ND
HCH, gamma	1.0	3.4	<RL	<RL
heptachlor	2.0	6.9	**UJ**	**UJ**
heptachlor epoxide	1.0	3.4	**5.26**	**1.48**
hexachlorobenzene	0.3	1.0	<RL	<RL
methoxychlor	5.0	17.2	ND	**ND**
mirex	3.0	10.3	ND	**ND**
nonachlor, cis	2.0	6.9	**11.5**	**3.24**
nonachlor, trans	1.0	3.4	**16.6**	**4.68**
oxadiazon	3.0	10.3	**35.2**	**9.93**
oxychlordane	1.0	3.4	ND	**ND**
parathion, ethyl	2.0	6.9	<RL	<RL
parathion, methyl	4.0	13.8	ND	**ND**
tedion	2.0	6.9	<RL	<RL
toxaphene	20.0	69.0	ND	**ND**
PCB 1248	25.0	86.2	<RL	<RL
PCB 1254	10.0	34.5	**333**	**93.9**
PCB 1260	10.0	34.5	**816**	**230**
Percent Moisture:			**71.8**	
Surrogates:			**% Recovery**	**Dry Wt. Dec. Fraction**
207			**95.8**	**0.282**
DBOB			**92.1**	
DDD*, p,p'			**77.1**	
DBCE			**89.9**	

***Dry Weight Reporting Limit based on the individual dry sample weight (2.90g).**

**** UJ = The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.**

Table 12
Pesticides and Aroclors – Yosemite Lake Sediment Duplicate

	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	Yosemite Lake Dup ppb (ng/g) Dry Weight	Yosemite Lake Dup ppb (ng/g) Fresh Weight
aldrin	1.0	3.4	<RL	<RL
chlordane, cis	2.0	6.8	**30.1**	**8.46**
chlordane, trans	2.0	6.8	**34.3**	**9.64**
chlordene, alpha	1.0	3.4	**4.90**	**1.38**
chlordene, gamma	1.0	3.4	<RL	<RL
chlorpyrifos	2.0	6.8	<RL	<RL
dacthal	2.0	6.8	<RL	<RL
DCBP, p,p'	10.0	33.9	ND	ND
DDD, o,p'	2.0	6.8	**39.7**	**11.2**
DDD, p,p'	2.0	6.8	**244**	**68.6**
DDE, o,p'	2.0	6.8	**9.85**	**2.77**
DDE, p,p'	2.0	6.8	**150**	**42.2**
DDMU, p,p'	3.0	10.2	**16.7**	**4.69**
DDT, o,p'	3.0	10.2	<RL	<RL
DDT, p,p'	5.0	16.9	**25.7**	**7.22**
diazinon	20.0	67.8	<RL	<RL
dieldrin	2.0	6.8	<RL	<RL
endosulfan I	2.0	6.8	ND	ND
endosulfan II	10.0	33.9	<RL	<RL
endosulfan sulfate	10.0	33.9	**UJ**	**UJ**
endrin	2.0	6.8	<RL	<RL
ethion	6.0	20.3	**UJ**	**UJ**
HCH, alpha	1.0	3.4	ND	ND
HCH, beta	2.0	6.8	ND	ND
HCH, gamma	1.0	3.4	<RL	<RL
heptachlor	2.0	6.8	**UJ**	**UJ**
heptachlor epoxide	1.0	3.4	**4.72**	**1.33**
hexachlorobenzene	0.3	1.0	<RL	<RL
methoxychlor	5.0	16.9	ND	ND
mirex	3.0	10.2	ND	ND
nonachlor, cis	2.0	6.8	**12.9**	**3.62**
nonachlor, trans	1.0	3.4	**18.3**	**5.14**
oxadiazon	3.0	10.2	**33.6**	**9.44**
oxychlordane	1.0	3.4	ND	ND
parathion, ethyl	2.0	6.8	ND	ND
parathion, methyl	4.0	13.6	<RL	<RL
tedion	2.0	6.8	<RL	<RL
toxaphene	20.0	67.8	ND	ND
PCB 1248	25.0	84.7	<RL	<RL
PCB 1254	10.0	33.9	**395**	**111**
PCB 1260	10.0	33.9	**953**	**268**
Percent Moisture:			**71.9**	
Surrogates:			**% Recovery**	**Dry Wt. Dec. Fraction**
207			**91.7**	**0.281**
DBOB			**93.9**	
DDD*, p,p'			**79.2**	
DBCE			**88.9**	

***Dry Weight Reporting Limit based on the individual dry sample weight (2.95g).**

**** UJ = The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.**

Table 13

Pesticides and Aroclors – Smith Canal: Mid Sediment

	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	**Smith Canal-Mid ppb (ng/g) Dry Weight**	**Smith Canal-Mid ppb (ng/g) Fresh Weight**
aldrin	1.0	2.8	ND	ND
chlordane, cis	2.0	5.6	**10.7**	**3.81**
chlordane, trans	2.0	5.6	**10.6**	**3.77**
chlordene, alpha	1.0	2.8	<RL	<RL
chlordene, gamma	1.0	2.8	<RL	<RL
chlorpyrifos	2.0	5.6	<RL	<RL
dacthal	2.0	5.6	<RL	<RL
DCBP, p,p'	10.0	27.8	ND	ND
DDD, o,p'	2.0	5.6	**12.8**	**4.56**
DDD, p,p'	2.0	5.6	**77.3**	**27.5**
DDE, o,p'	2.0	5.6	<RL	<RL
DDE, p,p'	2.0	5.6	**56.7**	**20.2**
DDMU, p,p'	3.0	8.3	<RL	<RL
DDT, o,p'	3.0	8.3	<RL	<RL
DDT, p,p'	5.0	13.9	**46.2**	**16.4**
diazinon	20.0	55.6	<RL	<RL
dieldrin	2.0	5.6	ND	ND
endosulfan I	2.0	5.6	ND	ND
endosulfan II	10.0	27.8	ND	ND
endosulfan sulfate	10.0	27.8	**UJ**	**UJ**
endrin	2.0	5.6	ND	ND
ethion	6.0	16.7	**UJ**	**UJ**
HCH, alpha	1.0	2.8	ND	ND
HCH, beta	2.0	5.6	ND	ND
HCH, gamma	1.0	2.8	ND	ND
heptachlor	2.0	5.6	**UJ**	**UJ**
heptachlor epoxide	1.0	2.8	<RL	<RL
hexachlorobenzene	0.3	0.8	<RL	<RL
methoxychlor	5.0	13.9	ND	ND
mirex	3.0	8.3	ND	ND
nonachlor, cis	2.0	5.6	<RL	<RL
nonachlor, trans	1.0	2.8	**6.34**	**2.26**
oxadiazon	3.0	8.3	<RL	<RL
oxychlordane	1.0	2.8	ND	ND
parathion, ethyl	2.0	5.6	ND	ND
parathion, methyl	4.0	11.1	ND	ND
tedion	2.0	5.6	<RL	<RL
toxaphene	20.0	55.6	ND	ND
PCB 1248	25.0	69.4	<RL	<RL
PCB 1254	10.0	27.8	**182**	**64.8**
PCB 1260	10.0	27.8	**290**	**103**
Percent Moisture:			**64.4**	
Surrogates:			**% Recovery**	**Dry Wt. Dec. Fraction**
207			**94.9**	**0.356**
DBOB			**88.7**	
DDD*, p,p'			**79.2**	
DBCE			**80.8**	

***Dry Weight Reporting Limit based on the individual dry sample weight (3.60g).**

**** UJ = The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.**

Table 14
Pesticides and Aroclors – Smith Canal: Mouth Sediment

	Fresh Weight Reporting Limit ppb (ng/g)	Dry Weight Reporting Limit* ppb (ng/g)	**Smith Canal-Mouth ppb (ng/g) Dry Weight**	**Smith Canal-Mouth ppb (ng/g) Fresh Weight**
aldrin	1.0	1.4	ND	ND
chlordane, cis	2.0	2.9	<RL	<RL
chlordane, trans	2.0	2.9	<RL	<RL
chlordene, alpha	1.0	1.4	ND	ND
chlordene, gamma	1.0	1.4	<RL	<RL
chlorpyrifos	2.0	2.9	ND	ND
dacthal	2.0	2.9	ND	ND
DCBP, p,p'	10.0	14.3	ND	ND
DDD, o,p'	2.0	2.9	<RL	<RL
DDD, p,p'	2.0	2.9	**3.18**	**2.07**
DDE, o,p'	2.0	2.9	<RL	<RL
DDE, p,p'	2.0	2.9	**3.83**	**2.50**
DDMU, p,p'	3.0	4.3	<RL	<RL
DDT, o,p'	3.0	4.3	ND	ND
DDT, p,p'	5.0	7.1	<RL	<RL
diazinon	20.0	28.6	ND	ND
dieldrin	2.0	2.9	ND	ND
endosulfan I	2.0	2.9	ND	ND
endosulfan II	10.0	14.3	ND	ND
endosulfan sulfate	10.0	14.3	**UJ**	**UJ**
endrin	2.0	2.9	ND	ND
ethion	6.0	8.6	**UJ**	**UJ**
HCH, alpha	1.0	1.4	ND	ND
HCH, beta	2.0	2.9	ND	ND
HCH, gamma	1.0	1.4	ND	ND
heptachlor	2.0	2.9	**UJ**	**UJ**
heptachlor epoxide	1.0	1.4	<RL	<RL
hexachlorobenzene	0.3	0.4	<RL	<RL
methoxychlor	5.0	7.1	ND	ND
mirex	3.0	4.3	ND	ND
nonachlor, cis	2.0	2.9	<RL	<RL
nonachlor, trans	1.0	1.4	<RL	<RL
oxadiazon	3.0	4.3	ND	ND
oxychlordane	1.0	1.4	ND	ND
parathion, ethyl	2.0	2.9	ND	ND
parathion, methyl	4.0	5.7	ND	ND
tedion	2.0	2.9	<RL	<RL
toxaphene	20.0	28.6	ND	ND
PCB 1248	25.0	35.7	<RL	<RL
PCB 1254	10.0	14.3	<RL	<RL
PCB 1260	10.0	14.3	<RL	<RL
Percent Moisture:			**34.8**	
Surrogates:			**% Recovery**	**Dry Wt. Dec. Fraction**
207			**94.2**	**0.652**
DBOB			**84.6**	
DDD*, p,p'			**78.1**	
DBCE			**85.4**	

***Dry Weight Reporting Limit based on the individual dry sample weight (7.00g).**

**** UJ = The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.**

The Smith Canal-Mid sediment sample had a similar mix of PCB congeners as did the Yosemite Lake sediment sample, with congeners 95, 101, 110, 138, 149, 151, 153, 170, 174, 177, 180 and 187 being present at > 10 ng/g. The total of the Smith Canal-Mid sediment PCB congeners was 379 ng/g. The sum of the Aroclors for the Smith Canal-Mid sediment sample was 472 ng/g, in good agreement with the sum of the congeners.

The Smith Canal-Mouth sediment sample showed significantly reduced congener content, with only congeners 138, 149, 153 and 180 present at greater than 1 ng/g. The total of the Smith Canal-Mouth PCB congeners was about 12 ng/g. The sum of the Aroclors for this sample was 35 ng/g.

The organochlorine pesticides analysis for the Yosemite Lake sediment sample shows elevated concentrations of cis- and trans-chlordane, at close to 30 ng/g, with a sum of the chlordanes at 58 ng/g. DDT analytes of note were as follows: DDD, o,p' at 35.6 ng/g, DDD, p,p' at 214 ng/g, DDE o,p' at 7.68 ng/g, DDE p,p' at 130 ng/g, and DDT p,p' at 19.9 ng/g. The sum of the DDTs was 193 ng/g.

Heptachlor epoxide was present in Smith Canal Yosemite Lake sediment samples (Table 11) at 5.26 ng/g, cis- and trans-nonochlor at 11.5 ng/g and 16.6 ng/g, respectively, and oxadiazon at 35.2 ng/g. Similar concentrations were found for these chemicals in the duplicate analyses. This same suite of organochlorine pesticides is typically found in waterbody sediments in the region where they have been used. Smith Canal samples did not contain measurable concentrations of diazinon or chlorpyrifos (the reporting limit for chlorpyrifos was 6.9 ng/g, and for diazinon was 69.0 ng/g). As discussed by Lee and Jones-Lee (2001), studies conducted by the CVRWQCB and the DeltaKeeper between 1994 and 1999 showed that Smith Canal waters were toxic due to diazinon and, sometimes, chlorpyrifos with each rainfall runoff event. Evidently, neither diazinon nor chlorpyrifos are accumulating and/or persisting in Smith Canal sediments.

The Smith Canal-Mid sample (Table 13) showed cis- and trans-chlordane at 10.7 ng/g and 10.6 ng/g, respectively. Also, the same suite of DDT and its transformation products were found in this sample as were found in the Yosemite Lake sample. The sum of the DDTs was about 7 ng/g. Nonochlor, cis-, was found at 6.34 ng/g.

Smith Canal-Mouth (Table 14) had small amounts of DDD, p,p' (3.18 ng/g) and DDE, p,p' (3.83 ng/g). All of the other organochlorine pesticides were present at concentrations below the reporting limit.

3.2.3 PCB Congeners, PCB Aroclors and Organochlorine Pesticides in *Lumbriculus variegatus* Tissues

A total of five samples were sent to the CA Department of Fish and Game Laboratory for PCB and OCl pesticide analysis. For each of these five samples, a total of five replicates (A-E) were provided. These replicate samples were composited for each sampling location. The tissue wet weight biomass values for each replicate are provided in Table 15.

Table 15. *Lumbriculus variegatus* biomass (g, wet weight) data					
	Rep A	Rep B	Rep C	Rep D	Rep E
T_0	5.33	4.46	4.31	5.84	3.53
Control	4.52	5.53	4.02	4.59	5.25
Yosemite Lake	2.64	2.28	2.16	1.84	2.61
SC - Mid-Channel	2.67	3.22	2.86	1.38	3.10
SC - Mouth	2.68	2.80	3.45	3.22	2.33

The organochlorine pesticides, PCB Aroclors and PCB congener bioaccumulation results are shown in Tables 16 and 17. Examination of these tables shows that the T_0 *Lumbriculus* worms (as received from the commercial supplier) contained DDE,p,p' at around 5 ng/g. There was a depuration of this DDE,p,p' down to about 2.3 ng/g in the control, after the 28-day exposure period. Several of the chlorinated hydrocarbon pesticides were taken up by the worm from the sediments. The tissue concentrations of cis- and trans-chlordane were 8.9 ng/g and 6.7 ng/g for Yosemite Lake, 5.5 ng/g and 3.7 ng/g for Smith Canal-Mid, and 2.5 ng/g and less than the reporting limit of 2.0 ng/g for Smith Canal-Mouth. The various DDT isomers and transformation products (except for DDT itself, which was not detected in the worm tissues, despite its presence in the sediments) were also taken up by the worms. There was uptake of cis- and trans-nonochlor from the Yosemite Lake sediments, and trans-nonochlor from the Smith Canal-Mid sample.

Duplicate analysis of the T_0 worms indicated Aroclor 1248 at 56 ng/g and 43 ng/g. There was depuration during the exposure period to less than the reporting limit of 25 ng/g, consistent with its absence from the sediments. However, Aroclors 1254 and 1260 were both accumulated by the worm from all three sediment samples, in general proportion to the amount of PCBs in the sediments.

Table 16 shows that there was significant bioaccumulation of various PCB congeners. The congeners found at the greatest concentrations in the sediments were, in general, those that were accumulated by the worms to the greatest extent. These included congeners 101, 138, 149, 151, 153 and 187, all of which were taken up to a level greater than 10 ng/g.

Examination of Table 16 shows, as expected, that the congener uptake by the worms for the Smith Canal-Mid and Smith Canal-Mouth was less than that for Yosemite Lake sediments, again, with those tending to be higher in the sediments exhibiting greater accumulation.

Total PCB congeners in the worms were 290 ng/g for Yosemite Lake, 161 ng/g for Smith Canal-Mid, and 72 ng/g for Smith Canal-Mouth. The sums of tissue Aroclors were 310 ng/g for Yosemite Lake, 168 ng/g for Smith Canal-Mid, and 83 ng/g for Smith Canal-Mouth. Again, there is remarkably good agreement between the sum of the Aroclors and the sum of the congeners.

Overall, it is concluded that some of the PCBs and organochlorine pesticides present in the sediments of Smith Canal, especially from Yosemite Lake, were bioavailable for uptake by the oligochaete *Lumbriculus variegatus*.

Table 16
PCB Congener Analysis of *Lumbriculus*

PCB congener	Reporting Limit Fresh Wt ppb (ng/g)	L-475-01 T(O) Fresh Wt. ppb (ng/g)	L-475-01 T(O) Dup Fresh Wt. ppb (ng/g)	L-475-01 Control Fresh Wt. ppb (ng/g)	L-475-01 YO Fresh Wt. ppb (ng/g)	L-475-01 SC Mid Fresh Wt. ppb (ng/g)	L-475-01 SC Mouth Fresh Wt. ppb (ng/g)
8	**0.2**	ND	ND	**0.348**	**0.273**	ND	ND
18	**0.2**	**0.782**	**0.572**	**0.431**	**0.334**	**0.222**	<RL
27	**0.2**	ND	ND	ND	ND	ND	ND
28	**0.2**	**2.23**	**1.73**	**1.52**	**0.902**	**0.604**	**0.433**
29	**0.2**	ND	ND	ND	ND	ND	ND
31	**0.2**	**2.01**	**1.53**	**1.56**	**0.704**	**0.430**	**0.352**
33	**0.2**	**0.688**	**0.519**	**0.652**	**0.403**	**0.260**	**<RL**
44	**0.2**	**6.06**	**4.73**	**2.85**	**1.50**	**1.03**	**0.743**
49	**0.2**	**3.66**	**2.83**	**1.69**	**3.02**	**1.47**	**0.750**
52	**0.2**	**5.97**	**4.61**	**2.95**	**3.80**	**2.01**	**1.13**
56	**0.2**	**1.49**	**1.31**	**0.840**	**0.226**	**0.275**	**0.241**
60	**0.2**	**0.704**	**0.610**	**0.375**	**0.159**	<RL	<RL
66	**0.2**	**3.71**	**2.93**	**1.78**	**1.23**	**0.954**	**0.689**
70	**0.2**	**4.04**	**3.21**	**2.52**	**1.32**	**0.930**	**0.655**
74	**0.2**	**1.60**	**1.21**	**0.820**	**0.885**	**0.499**	**0.306**
87	**0.2**	**1.11**	**0.892**	**0.611**	**1.62**	**1.12**	**0.687**
95	**0.2**	**2.26**	**1.89**	**1.08**	**7.16**	**4.29**	**2.03**
97	**0.2**	**0.926**	**0.742**	**0.467**	**0.883**	**0.666**	**0.457**
99	**0.2**	**1.14**	**0.908**	**0.551**	**4.09**	**2.57**	**1.34**
101	**0.2**	**2.30**	**1.82**	**1.09**	**11.8**	**7.68**	**3.52**
105	**0.2**	**0.476**	**0.439**	**0.288**	**ND**	**0.460**	**0.375**
110	**0.2**	**2.81**	**2.29**	**1.42**	**8.35**	**5.45**	**3.02**
114	**0.2**	ND	ND	ND	<RL	ND	ND
118	**0.2**	**1.45**	**1.24**	**0.729**	**3.19**	**2.35**	**1.57**
128	**0.2**	<RL	<RL	<RL	**1.61**	**1.08**	**0.607**
137	**0.2**	ND	ND	ND	<RL	<RL	ND
138	**0.2**	**1.43**	**1.28**	**0.584**	**42.2**	**22.3**	**10.0**
141	**0.2**	ND	ND	ND	**3.41**	**1.39**	**0.278**
149	**0.2**	**1.03**	**0.885**	**0.410**	**39.9**	**19.9**	**8.20**
151	**0.2**	**0.401**	**0.324**	<RL	**17.4**	**10.1**	**4.07**
153	**0.2**	**1.27**	**1.12**	**0.585**	**40.3**	**21.2**	**9.15**
156	**0.2**	<RL	<RL	ND	**1.52**	**0.768**	**0.426**
157	**0.2**	ND	ND	ND	**0.389**	**0.243**	<RL
158	**0.2**	ND	ND	ND	**2.01**	**1.08**	**0.431**
170	**0.2**	<RL	<RL	ND	**9.19**	**5.02**	**1.96**
174	**0.2**	<RL	<RL	ND	**10.1**	**5.09**	**1.76**
177	**0.2**	<RL	<RL	ND	**7.62**	**4.61**	**2.15**
180	**0.2**	ND	ND	ND	**5.75**	**2.15**	**0.494**
183	**0.2**	<RL	<RL	ND	**5.63**	**2.92**	**1.08**
187	**0.2**	**0.596**	**0.534**	**0.262**	**37.6**	**21.5**	**9.23**
189	**0.2**	ND	ND	ND	**0.391**	**0.230**	<RL
194	**0.2**	ND	ND	ND	**2.31**	**1.30**	**0.452**
195	**0.2**	ND	ND	ND	**1.63**	**0.978**	**0.468**
200	**0.2**	ND	ND	ND	**0.565**	**0.378**	**0.216**
201	**0.2**	<RL	<RL	<RL	**4.96**	**3.19**	**1.57**
203	**0.2**	<RL	<RL	ND	**2.84**	**1.80**	**0.979**
206	**0.2**	<RL	<RL	<RL	**0.533**	**0.396**	**0.245**
209	**0.2**	<RL	<RL	<RL	<RL	<RL	<RL
Surrogate:		**% Recovery**	**% Recovery**	**% Recovery**	**% Recovery**	**% Recovery**	**% Recovery**
207		**91.9**	**96.8**	**90.4**	**95.5**	**97.6**	**95.2**

Table 17
Organochlorine Pesticides and Aroclors in *Lumbriculus*

	Reporting Limit Fresh Wt ppb (ng/g)	L-475-01 T(O) Fresh Wt ppb (ng/g)	L-475-01 T(O) Dup Fresh Wt ppb (ng/g)	L-475-01 Control Fresh Wt ppb (ng/g)	L-475-01 YO Fresh Wt ppb (ng/g)	L-475-01 SC Mid Fresh Wt ppb (ng/g)	L-475-01 SC Mouth Fresh Wt ppb (ng/g)
aldrin	**1.0**	ND	ND	ND	<RL	<RL	ND
chlordane, cis	**2.0**	<RL	<RL	<RL	**8.91**	**5.46**	**2.54**
chlordane, trans	**2.0**	<RL	<RL	<RL	**6.66**	**3.71**	<RL
chlordene, alpha	**1.0**	<RL	<RL	<RL	**1.40**	<RL	<RL
chlordene, gamma	**1.0**	<RL	<RL	<RL	<RL	<RL	<RL
chlorpyrifos	**2.0**	ND	ND	ND	<RL	ND	ND
dacthal	**2.0**	ND	ND	ND	ND	ND	ND
DCBP, p,p'	**10.0**	ND	ND	ND	<RL	<RL	<RL
DDD, o,p'	**2.0**	<RL	<RL	<RL	**9.50**	**4.94**	<RL
DDD, p,p'	**2.0**	<RL	<RL	<RL	**56.1**	**29.1**	**9.78**
DDE, o,p'	**2.0**	<RL	ND	ND	**2.52**	<RL	<RL
DDE,p,p'	**2.0**	**5.47**	**4.82**	**2.26**	**55.2**	**39.0**	**28.8**
DDMU, p,p'	**3.0**	<RL	<RL	<RL	**6.25**	**4.72**	<RL
DDT, o,p'	**3.0**	ND	ND	ND	ND	ND	ND
DDT, p,p'	**5.0**	ND	ND	ND	<RL	<RL	ND
diazinon	**20.0**	ND	ND	ND	ND	ND	ND
dieldrin	**2.0**	<RL	<RL	<RL	ND	ND	<RL
endosulfan I	**2.0**	ND	ND	ND	ND	ND	ND
endosulfan II	**10.0**	ND	ND	ND	<RL	ND	ND
endosulfan sulfate	**10.0**	ND	ND	<RL	<RL	ND	<RL
endrin	**2.0**	ND	ND	ND	ND	ND	ND
ethion	**6.0**	ND	ND	ND	ND	ND	ND
HCH, alpha (F1+F2)	**1.0**	ND	ND	ND	ND	ND	ND
HCH, beta	**2.0**	ND	ND	ND	ND	ND	ND
HCH, gamma	**1.0**	ND	ND	ND	ND	ND	ND
heptachlor	**2.0**	ND	ND	ND	ND	ND	ND
heptachlor epoxide	**1.0**	<RL	<RL	<RL	<RL	<RL	<RL
hexachlorobenzene	**0.3**	<RL	<RL	<RL	<RL	<RL	<RL
methoxychlor	**5.0**	ND	ND	ND	ND	ND	ND
mirex	**3.0**	ND	ND	ND	ND	<RL	<RL
nonachlor, cis	**2.0**	<RL	<RL	<RL	**2.77**	<RL	<RL
nonachlor, trans	**1.0**	<RL	<RL	<RL	**3.16**	**1.64**	<RL
oxadiazon	**3.0**	ND	ND	ND	<RL	<RL	<RL
oxychlordane	**1.0**	<RL	<RL	ND	ND	ND	ND
parathion, ethyl	**2.0**	ND	ND	ND	ND	ND	ND
parathion, methyl	**4.0**	ND	ND	ND	ND	ND	ND
tedion	**2.0**	ND	ND	ND	ND	ND	ND
toxaphene	**20.0**	ND	ND	ND	ND	ND	ND
PCB 1248	**25**	**56**	**43**	**39**	<RL	<RL	<RL
PCB 1254	**10**	**12**	**11**	<RL	**180**	**86**	**44**
PCB 1260	**10**	<RL	<RL	ND	**130**	**82**	**39**
Percent Moisture		**86.0**	**IS**	**86.1**	**IS**	**84.5**	**84.3**
Percent Lipid		**1.69**	**1.80**	**1.58**	**1.77**	**1.55**	**0.364**
Surrogates		**% Recovery**	**% Recovery**	**% Recovery**	**% Recovery**	**% Recovery**	**% Recovery**
207		**98.5**	**103.6**	**96.8**	**102.3**	**104.6**	**102.1**
DBOB		**84.9**	**94.0**	**88.9**	**87.1**	**90.9**	**88.0**
DDD*, p,p'		**95.4**	**90.7**	**84.5**	**83.6**	**82.3**	**85.5**
DBCE		**94.4**	**88.7**	**97.2**	**97.2**	**98.1**	**97.2**

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Appendix B
Literature Review

This literature review on *Lumbriculus* and Bioaccumulation was compiled by Dr. V. McFarland of the US Army Corps of Engineers Engineering Research and Development Center Waterways Experiment Station, Vicksburg, MS.

Ankley, Gerald T.; Cook, Philip M.; Carlson, Anthony R.; Call, Daniel J.; Swenson, Julie A.; Corcoran, Henry R., and Hoke, Robert A. (1992). bioaccumulation of pcbs from sediments by oligochaetes and fishes: comparison of laboratory and field studies. *Canadian Journal of Fisheries and Aquatic Science*. 49, 2080-2085.

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Authors: Fisher, SW; Chordas, SW; Landrum, PF
Title: Lethal and sublethal body residues for PCB intoxication in the oligochaete, Lumbriculus variegatus
Source: AQUATIC TOXICOLOGY, 45 (2-3): 115-126 APR 1999
Abstract: The oligochaete, Lumbriculus variegatus, was used to examine the utility of critical body residues in describing lethal and sublethal chronic endpoints during polychlorinated biphenyls (PCB)

exposure. L. variegatus was exposed to four C-14-PCB congeners and 2,2-bis-(p-chlorophenyl)-1,1-dichloroethylene (DDE) on algal cells. Accumulation and resulting effects were monitored in 10-day acute and 35-day chronic exposures. L. variegatus was resistant to the acute lethal narcotic effects of these contaminants and no mortality was obtained in 10-day exposures. However, mortality that was significantly different from unexposed controls occurred for four compounds in 35-day assays; average body residues for chronic mortality were consistent among contaminants (0.88-1.35 mmol kg(-1)). Kinetic studies showed that failure to generate mortality in some exposures was due to rapid elimination. Mono-2-chlorobiphenyl, for instance, had a K-d of 0.22 h(-1) which was seven to 44 times faster than for the other contaminants. Sublethal reductions in body mass and reproduction occurred at lower body residues than were needed to produce mortality (0.34-0.56 mmol kg(-1)). The consistency of the sublethal data suggests that they may offer a means of interpreting residue data for PCBs in the environment.

Authors: Brunson, EL; Canfield, TJ; Dwyer, FJ; Ingersoll, CG; Kemble, NE
Title: Assessing the bioaccumulation of contaminants from sediments of the upper Mississippi River using field-collected oligochaetes and laboratory-exposed Lumbriculus variegatus
Source: ARCHIVES OF ENVIRONMENTAL CONTAMINATION AND TOXICOLOGY, 35 (2): 191-201 AUG 1998
Abstract: Concern with the redistribution of contaminants associated with sediment in the upper Mississippi River (UMR) arose after the flood of 1993. This project is designed to evaluate the status of sediments in the UMR and is one article in a series designed to assess the extent of sediment contamination in navigational pools of the river. Companion articles evaluate sediment toxicity and benthic community composition in navigation pools of the river. The objectives of the present study were to: (1) to assess the bioaccumulation of sediment-associated contaminants in the UMR using laboratory exposures with the oligochaete Lumbriculus variegatus, and (2) to compare bioaccumulation in laboratory-exposed oligochaetes to field-collected oligochaetes. Sediment samples and native oligochaetes were collected from 23 navigational pools on the Upper Mississippi River and the Saint Croix River. Contaminant concentrations measured in the L. variegatus after 28-day exposures to sediment in the laboratory were compared to contaminant concentrations in field-collected oligochaetes from the 13 pools where these sediments were collected. Contaminant concentrations were relatively low in sediments and tissues from the pools evaluated. Only polycyclic aromatic hydrocarbons (PAHs) and total polychlorinated biphenyls (PCBs) were frequently measured above detection limits. The majority of the biota-sediment-accumulation factors (BSAFs) for PAHs were within a range of about 1.0 to 2.6, suggesting that the theoretical BSAF value of 1.7 could be used to predict these mean BSAFs with a reasonable degree of certainty. A positive correlation was observed between lipid-normalized concentrations of PAHs detected in laboratory-exposed and field-collected oligochaetes across all sampling locations. Rank correlations for concentrations of individual compounds between laboratory-exposed and field-collected oligochaetes were strongest for benzo(e)pyrene, perylene, benzo(b,k)fluoranthene, and pyrene. About 90% of the paired PAH concentrations in laboratory-exposed and field-collected oligochaetes were within a factor of three of one another indicating laboratory results could be extrapolated to the field with a reasonable degree of certainty.

Authors: Winger, PV; Lasier, PJ; White, DH; Seginak, JT
Title: Effects of contaminants in dredge material from the lower Savannah River
Source: ARCHIVES OF ENVIRONMENTAL CONTAMINATION AND TOXICOLOGY, 38 (1): 128-136 JAN 2000
Abstract: Contaminants entering aquatic systems from agricultural, industrial, and municipal activities are generally sequestered in bottom sediments. The environmental significance of contaminants associated with sediments dredged from Savannah Harbor, Georgia, USA, are unknown. To evaluate potential effects of contaminants in river sediments and sediments dredged and stored in upland disposal areas on fish and wildlife species, solid-phase sediment and sediment pore water from Front River, Back River, an unnamed Tidal Creek on Back River, and Middle River of the distributary system of the lower Savannah River were tested for toxicity using the freshwater amphipod Hyalella azteca. In addition, bioaccumulation of metals from sediments collected from two dredge-disposal areas was determined using the freshwater oligochaete Lumbriculus variegatus. Livers from green-winged teals (Anas crecca) and lesser yellowlegs (Tringa flavipes) foraging in the dredge-spoil areas and raccoons (Procyon later) from the dredge-disposal/river area and an upland site were collected for metal analyses. Survival of H. azteca was not reduced in solid-phase sediment exposures, but was reduced in pore water from several locations receiving drainage from dodge-disposal areas. Basic water chemistry (ammonia, alkalinity, salinity) was responsible for the reduced survival at several sites, but PAHs, metals, and other unidentified factors were responsible at other sites. Metal residues in sediments from the Tidal Creek and Middle River reflected drainage or seepage from adjacent dredge-disposal areas, which could potentially reduce habitat quality in these areas. Trace metals increased in L. variegatus exposed in the laboratory to dredge-disposal sediments; As, Cu, Hg, Se, and Zn bioaccumulated to concentrations higher than those in the sediments. Certain metals (Cd, Hg, Mo, Se) were higher in livers of birds and raccoons than those in dredge-spoil sediments suggesting bioavailability. Cadmium, Cr, Hg, Pb, and Se in livers from raccoons collected near the river and dredge-disposal areas were significantly higher than those of raccoons from the upland control site. Evidence of bioaccumulation from laboratory and field evaluations and concentrations in sediments from dredge-disposal areas and river channels demonstrated that some metals in the dredge-disposal areas are mobile and biologically available. Drainage from dredge-disposal areas may be impacting habitat quality in the river, and fish and wildlife that feed and nest in the disposal areas on the lower Savannah River may be at risk from metal contamination.

Authors: Nuutinen, S; Kukkonen, JVK
Title: The effect of selenium and organic material in lake sediments on the bioaccumulation of methylmercury by Lumbriculus variegatus (oligochaeta)
Source: BIOGEOCHEMISTRY, 40 (2-3): 267-278 MAR 1998
Abstract: The accumulation of methylmercury (MeHg) to an oligochaete worm Lumbriculus variegatus (Muller) was measured in two different lake sediments in the laboratory. C-14- labelled MeHg was added to sediments at the nominal concentration of 95 ng/g dw sediment. Groups of six oligochaete worms were exposed in glass beakers to 35 g of spiked sediment for 14 days. The two sediments had organic carbon concentrations of 3.4% and 9.9% and natural selenium concentrations of 1.45 and 0.28 mg/kg (dw), respectively. After two weeks exposure, both the accumulation rate of MeHg and the body residue in the worms were much lower in the sediment having a high organic

carbon content. The effect of selenium concentration in the sediment on bioaccumulation of MeHg in Lumbriculus variegatus was measured in one sediment (organic carbon 3.4% and Se 1.45 mg/kg) by adding sodiumselenite (Na2SeO3) at different concentrations. The added amounts of selenium were 0, 0.1, 0.5, 2.5, 15.0, and 50.0 mg Se/kg dry sediment. In this exposure the nominal concentration of MeHg was 102 ng/g dw sediment. The two lowest selenium concentrations did not affect the bioaccumulation of MeHg. But, the dose of 2.5 mg Se/kg resulted in a 25% reduction in the body residue after two weeks exposure. When 15 and 50 mg Se/kg were added to the sediment the accumulation of MeHg in the organisms was decreased by 75% and 86%, respectively, as compared to the reference.

Authors: Conrad, AU; Comber, SD; Simkiss, K
Title: New method for the assessment of contaminant uptake routes in the oligochaete Lumbriculus variegatus
Source: BULLETIN OF ENVIRONMENTAL CONTAMINATION AND TOXICOLOGY, 65 (1): 16-21 JUL 2000

Authors: Lawrence, MAM; Davies, NA; Edwards, PA; Taylor, MG; Simkiss, K
Title: Can adsorption isotherms predict sediment bioavailability?
Source: CHEMOSPHERE, 41 (7): 1091-1100 OCT 2000
Abstract: The adsorption and desorption of 2,4-dichlorophenol (DCP) and pentachlorophenol (PCP) were studied for a range of synthetic particles, a dimethylditallowammonium exchanged clay and a natural sediment. The synthetic particles were Dowex 1X8400, Toyopearl Phenyl 650M and Toyopearl SP 650M. The bioaccumulation of the DCP and PCP from these particles was then studied using the oligochaete, Lumbriculus variegatus. There is a correlation between contaminant-particle interactions, as determined from adsorption and desorption isotherms, and bioaccumulation. Bioaccumulation by L. variegatus was found to be highest from the systems where differences in the classification of adsorption and desorption isotherms were observed.

Authors: Simkiss, K; Davies, NA; Edwards, PA; Lawrence, MAM; Taylor, MG
Title: The use of sediment analogues to study the uptake of pollutants by chironomid larvae
Source: ENVIRONMENTAL POLLUTION, 115 (1): 89-96 2001
Abstract: A technique is described that uses artificial resin beads with known surface properties to investigate the factors influencing the bioaccumulation of pollutants from sediments. One advantage of this technique is that it provides a standard procedure against which it is possible to calibrate natural sediments with their diverse properties. The method has been used on third instar larvae of the midge Chironomus riparius and the results are compared with previous studies on the worm Lumbriculus variegatus. The use of a standard test using resin beads as a substitute for natural sediment allows comparisons to be made between species and substrates. Thus, the bioaccumulation factors for the midge larvae are much smaller than those of the worm and this correlates with the ability of the insect larva to detoxify many pollutants. It is also possible to use the test to identify if ingestion of the sediment increases the bioaccumulation of contaminants and whether this involves the release of pollutants by digestive processes or not.

Authors: Reid, BJ; Jones, KC; Semple, KT
Title: Bioavailability of persistent organic pollutants in soils and sediments - a perspective on mechanisms, consequences and assessment
Source: ENVIRONMENTAL POLLUTION, 108 (1): 103-112 2000
Abstract: It has been observed that as soil-pollutant contact time increases, pollutant bioavailability and extractability decreases. This phenomenon has been termed 'ageing'. Decreased chemical extractability with increased soil-chemical contact time is evident where both 'harsh' techniques, e.g. dichloromethane Soxhlet extraction, and 'non-exhaustive' techniques, e.g. butanol shake extraction, have been used. It has also been observed that the amount of chemical extracted by these techniques varies considerably over time. Similarly, decreases in bioavailability with increased soil-pollutant contact time have been described in bacterial, earthworm and other organism studies. From these investigations, it has been shown that the fraction of pollutant determined to be bioavailable can vary between organisms. Thus, there is an immediate definition problem, what is bioavailability? Additionally, if bioavailability is to be assessed by a chemical means, which organisms should (or can) be mimicked by the extraction procedure? This review provides a background to the processes inherent to ageing, a discussion of its consequences on bioavailability and ends with some reflections on the appropriateness of chemical extraction techniques to mimic bioavailability (C) 2000 Elsevier Science Ltd. All rights reserved.

Authors: Bott, TL; Standley, LJ
Title: Transfer of benzo[a]pyrene and 2,2 ',5,5 ' tetrachlorobiphenyl from bacteria and algae to sediment-associated freshwater invertebrates
Source: ENVIRONMENTAL SCIENCE & TECHNOLOGY, 34 (23): 4936-4942 DEC 1 2000
Abstract: Feeding interactions between microorganisms and their grazers range from broad and general to very specific. Here we examined routes of transfer of [H-3]benzo[a]pyrene (BaP) and 2,2',5,5'[C-14]tetrachlorobiphenyl (PCB-52) from microorganisms in freshwater sediments to oligochaetes (Lumbriculus variegatus) and chironomid larvae (either Stictochironomus sp. or a mix of smaller taxa) when exposed to the compounds added either directly to sediments or to bacteria or diatoms previously labeled and then added to sediments. The appearance of radiolabel in animals after a gut clearing step to differentiate between ingested and absorbed compound was followed in time course experiments. Relative to the added radiolabel, BaP concentrations were greater than PCB concentrations in L. variegatus and were greater in animals fed radiolabeled sediments or bacteria than those offered diatoms. In contrast, the chironomids accumulated more PCB than BaP. The mix of small chironomids bioaccumulated more PCB when fed prelabeled algae than when fed sediment or bacteria. However, Stictochironomus sp. bioaccumulated more from sediments and/or bacteria. Food selection influences pathways of contaminant transfer, even to small animals at the base of the food web. We also tested whether the bioaccumulation of BaP and PCB would be predicted by the K-oc for the sediment (i.e., BCF/K-oc = 1). The quotients, averaged over experiments, were 1.08 and 1.53 for PCB-52 and BaP, respectively, hut error terms were large, with coefficients of variation being 83% and 135%, respectively.

Authors: Leppanen, MT; Kukkonen, JVK
Title: Relative importance of ingested sediment and pore water as bioaccumulation routes for pyrene to oligochaete (Lumbriculus variegatus, Muller)
Source: ENVIRONMENTAL SCIENCE & TECHNOLOGY, 32 (10): 1503-1508 MAY 15 1998
Abstract: It is generally accepted that sediment ingestion is an important route in accumulation of highly hydrophobic sediment-bound contaminants. The significance of this route is, however, difficult to quantify reliably. For this purpose, the relative importance of pare water and ingested sediment as sources was studied by exposing individual oligochaetes of different size to radiolabeled pyrene spiked lake sediment for 28 days. Simultaneously, their ingestion behavior (ingestion rate) was followed. The design allowed comparison of the bioaccumulation process between individuals ingesting and noningesting sediment. Pyrene accumulated mainly th ro ugh ingested material. After 8 days of exposure, approximately 61% of the body burden had accumulated via ingested material. Uptake clearance rates differed between worm groups, which started sediment ingestion at different points of time. This was probably due to decreasing bioavailability. The data signify the importance of ingested material in bioaccumulation of hydrophobic chemicals in deposit feeders. The method offers a biologically sound and reliable tool for assessing the bioavailability of chemicals from pore water and ingested sediment for Lumbriculus variegatus.

Authors: Van Hoof, PL; Kukkonen, JVK; Landrum, PF
Title: Impact of sediment manipulation on the bioaccumulation of polycyclic aromatic hydrocarbons from field-contaminated and laboratory-dosed sediments by an oligochaete
Source: ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY, 20 (8): 1752-1761 AUG 2001
Abstract: The accumulation kinetics of polycyclic aromatic hydrocarbons (PAHs) by the freshwater oligochaete Lumbriculus variegatus were measured for field-contaminated and laboratory-dosed sediment. In addition, sediment manipulations typically used for homogenization and dosing in bioaccumulation assays were compared. Rather than an asymptotic approach to steady state, both resident and dosed PAH accumulation exhibited a peak during the 14-d assays, with steeper declines being noted for the lower-molecular-weight compounds. Lack of evidence of a peak for higher-molecular-weight PAHs may be due to slower kinetics and the short length of the assay. Relative to minimally mixed sediment, slurried sediment enhanced the accumulation of less-soluble resident PAHs, did not affect moderately soluble PAHs, and reduced the uptake of the more-soluble PAHs, fluorene and phenanthrene. Aging sediment after mixing reduced the availability of highly to moderately soluble resident PAHs but had no effect on less-soluble PAHs. A similar effect was noted for dosed PAHs, though a larger reduction in bioavailability was observed. Dosed PAH uptake clearance coefficients (k(s)) exceeded those of minimally mixed resident PAHs by factors of 3 to 4 for pyrene and 26 for benzo[a]pyrene. These results demonstrate that sediment manipulations and contamination history need to be considered when measuring PAH bioaccumulation.

Authors: Sibley, PK; Benoit, DA; Balcer, MD; Phipps, GL; West, CW; Hoke, RA; Ankley, GT
Title: In situ bioassay chamber for assessment of sediment toxicity and bioaccumulation using benthic invertebrates
Source: ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY, 18 (10): 2325-2336 OCT 1999
Abstract: In this study, we describe the construction of a simple, inexpensive bioassay chamber for testing sediment toxicity (survival and growth) and bioaccumulation under field conditions using the midge Chironomus tentans and the oligochaete Lumbriculus variegatus. The test chamber is comprised of a Lexan(R) or Plexiglass(TM) core tube containing several screened ports to facilitate water exchange. A rubber stopper, equipped with a small plastic holding vessel to hold organisms, is secured on top of the test chamber before deploying the tube. Once the test chamber is pushed into the sediment to a depth of approximately 20 cm, the bioassay is initiated by releasing the test organisms from the holding chamber into the rest chamber. We evaluated the performance of this in situ bioassay system by conducting 10-d exposures at two contaminated and two reference sites, and in a transplanted control sediment. Performance in the field test was compared to parallel 10-d laboratory tests. Survival of C. tentans was 68 and 72% at the two reference sites. Corresponding survival in these sediments in laboratory tests was 96 and 75%. Survival in the transplanted control sediment was 97%. Although significant differences between sediments in the absolute values of survival and growth were observed in both field and laboratory exposures to contaminated sediments, the relative pattern of response for these endpoints was comparable between the laboratory and the field. Variability (coefficient of variation) associated with both survival and growth was generally greater in field exposures (20-86%) than in laboratory exposures (5-72%). A portion of this variability seemed to reflect the occurrence of predatory species, because we observed a significant relationship between the number of predatory species and survival of C. tentans. In tests with L. variegatus, survival of worms was 85% in the reference sediment and 40 to 76% in two contaminated sediments. At all sites, a sufficient tissue mass of worms was collected after 10 d to facilitate assessment of bioaccumulation. The results of this study demonstrate that the proposed in situ bioassay can be used successfully to assess toxicity and bioaccumulation in contaminated sediments.

Authors: Mount, DR; Dawson, TD; Burkhard, LP
Title: Implications of gut purging for tissue residues determined in bioaccumulation testing of sediment with Lumbriculus variegatus
Source: ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY, 18 (6): 1244-1249 JUN 1999
Abstract: Bioaccumulation test procedures using the oligochaete Lumbriculus variegatus have been developed as a means of evaluating the accumulation of chemicals from freshwater sediments. To avoid including chemicals associated with gut contents as part of the measured tissue residue, a 24-h period of purging in clean water after the uptake phase of the test has been recommended. While purging acts to reduce bias from gut contents, it also has the potential to introduce bias caused by depuration of chemicals from tissues. In this paper, a series of model calculations are used to assess the expected sensitivity of measured residues of nonionic organic chemicals to the presence of sediment in the gut and to varying lengths of purging. If organisms an not purged, the predicted influence of gut contents on measured residue is not large (generally <20%) when a biota-sediment accumulation factor

(BSAF) of one is assumed. However, if BSAFs substantially less than one apply, projected errors increase to 30-fold or more. To derive a better estimate of the time required for L. variegatus to clear the gut of sediment, a sediment purging experiment was conducted; results indicate that >98% of sediment had cleared the gut in 6 h (half-life = 0.98 h). Based on these results and model analyses, a much shorter purging period of 6 h, rather than 24 h, is suggested as a reasonable guideline for many test applications.

Authors: Fisk, AT; Wiens, SC; Webster, GRB; Bergman, W; Muir, DCG
Title: Accumulation and depuration of sediment-sorbed C-12- and C-16-polychlorinated alkanes by oligochaetes (Lumbriculus variegatus)
Source: ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY, 17 (10): 2019-2026 OCT 1998
Abstract: Oligochaetes (Lumbriculus variegatus) were exposed to sediment spiked with four C-14-polychlorinated alkanes (PCAs) (C12H20Cl6 [56% Cl by weight], C12H16Cl10 [69% Cl], C16H31Cl3 [35% Cl], and C16H21Cl13 [69% CI]) to measure bioaccumulation parameters and biotransformation. Chlorinated paraffins are industrial products that consist of thousandsof different PCAs. Chlorinated paraffins are hydrophobic (log octanol-water partition coefficients [K(ow)s] > 5.0) and are reported to have relatively high concentrations in sediment compared with other persistent organochlorines; however, no data exist on their bioavailability from sediment. The PCAs C12H20Cl6, C12H16Cl10, and C16H31Cl3 were readily available to sediment-ingesting oligochaetes, whereas C16H21Cl13 had lower bioavailability. Uptake rates of the C-12-PCAs were greater than the C-16-PCAs, but half-lives (t(1/2)s) were greater for the C-16-PCAs (t(1/2) = 30-33 d) than for the C-12-PCAs (t(1/2) = 12-14 d). Biota-sediment accumulation factors were >1 for C12H20Cl6, C12H16Cl10, and C16H31Cl3, but <1 for C16H21Cl13. Comparison of toluene-extractable and -nonextractable C-14 suggest that PCAs were biotransformed in aerobic sediments and by oligochaetes, and that the susceptibility to degradation in sediments decreases with increasing chlorine content. The relative abundance of individual PCAs may differ between sediment and benthic invertebrates because of differences in the bioaccumulation and degradation of PCAs of varying carbon chain length and chlorine content.

Authors: Schuler, LJ; Lydy, MJ
Title: Chemical and biological availability of sediment-sorbed benzo[a]pyrene and hexachlorobiphenyl
Source: ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY, 20 (9): 2014-2020 SEP 2001
Abstract: This study examined the chemical and biological availability of two nonpolar organic compounds, benzo[a]pyrene (BaP) and hexachlorobiphenyl (HCBP), from a spiked sediment that was aged for varying amounts of time. Chemical availability was evaluated using four different solvent combinations to extract chemicals from the sediment. The extractability of BaP and HCBP from sediment using traditional solvents was then compared to the transfer efficiency (TE) of a benthic invertebrate (Lumbriculus variegatus) to relate chemical extractability to bioavailability in the organisms. Results indicated that water was the solvent that best approximated bioavailability for BaP, whereas comparisons for HCBP were inappropriate, because TE values exceeded 100%. The inability to obtain

a reasonable TE estimate for HCBP was most likely due to the fact that the oligochaetes received a major portion of their uptake from interstitial water instead of ingestion of sediment particles, which invalidated an important assumption of the TF, model. Overall, the results of this study indicate that exhaustive chemical extractions may be an inaccurate representation of the bioavailable fractions for some contaminants.

Authors: Pickard, SW; Yaksich, SM; Irvine, KN; McFarland, VA
Title: Bioaccumulation potential of sediment-associated polychlorinated biphenyls (PCBs) in Ashtabula Harbor, Ohio
Source: JOURNAL OF GREAT LAKES RESEARCH, 27 (1): 44-59 2001
Abstract: Ashtabula Harbor Ohio is designated as a Great Lakes Ar-ea of Concern contaminated by PCBs. Information on the bioaccumulation of PCBs from sediments is important for sediment management strategies such as dredging to restore navigable depths in the harbor. To ascertain the bioaccumulation of these PCBs, the aquatic earthworm Lumbriculus variegatus tc as exposed in the laboratory to contaminated sediments collected from 15 areas in the harbor. Data from these bioaccumulation experiments were used to determine the bioaccumulation potential of PCBs through the calculation of Biota-Sediment Accumulation Factors (BSAFs). The results showed that the mean values of the experimentally? derived BSAFs for individual harbor areas ranged from 0.27 to 1.69. The median BSAF for sediments in the lower river sector of the harbor (0.38) was significantly lower than that for upper river sediments (1.34), indicating that the high adsorptive properties of coal soot particles constrained PCB bioavailability in the lower river sediments. These results indicate that the origin of total organic carbon (TOC) has a major influence on the bioavailability of total PCBs in harbor sediments. Moreover, the empirical BSAFs were well below the 4.0 default BSAF value recommended in joins USEPA/USACE protocols that are used to evaluate tire Theoretical Bioaccumulation Potential, or bioavailability, of neutral organic chemicals in Great Lakes sediments. These empirical values should be used to more precisely predict the bioavailability of total PCBs in Ashtabula Harbor sediments.

Appendix C
Biographical Information on Investigators

Drs. G. Fred Lee and Anne Jones-Lee

Dr. G. Fred Lee is President of G. Fred Lee & Associates (EnviroQual) a specialty water quality consulting firm, located in El Macero, CA (next to Davis, CA). He and Dr. Anne Jones-Lee (his wife) are the two principals in the firm. After obtaining a bachelor's degree at San Jose State University in 1955, a Master of Science Degree in Public Health from the University of North Carolina in 1957 and a PhD from Harvard University in 1960 in Environmental Engineering and Environmental Sciences, Dr. Lee taught graduate-level university environmental engineering and environmental science courses for 30 years at several major US universities. During this time, he conducted over $5 million of research and published over 500 papers and reports.

Dr. Anne Jones-Lee was a university professor for a period of 11 years in environmental engineering and environmental sciences. At the New Jersey Institute of Technology she held the position of Associate Professor of Civil and Environmental Engineering with tenure. She has a B.S. degree in biology from Southern Methodist University and a Ph.D in Environmental Sciences from the University of Texas at Dallas, which was obtained in 1978.

Dr G. F. Lee's previous work on pesticides has included driving a spray rig, university research, serving on a state pesticide regulatory board and as an advisor to national committees/ organizations on regulating pesticides. Dr. G. F. Lee has been working on excessive bioaccumulation of OCls in fish tissue for over 30 years. During the 30 years that he held university professorial positions at several major US universities, he conducted research on the transport, fate and effects of bioaccumulatable OCls (organochlorine pesticides such as DDT, aldrin, dieldrin, toxaphene, etc., and PCBs). It was Dr. Lee and his graduate students, at the University of Wisconsin, Madison, who were among the first to identify PCBs as widespread pollutants in water, sediments and fish tissue.

Dr. Lee's involvement with organochlorine pesticides started in the early 1950s, where, while working on a grape ranch near Delano, California, he drove spray rigs for application of pesticides to grapes. In the mid-1950s, while an intern in the City of San Jose Department of Health, he was involved in a summer project that utilized organochlorine pesticides and other chemicals for mosquito control.

In the 1960s, Dr. Lee led several research projects devoted to the water quality aspects of organochlorine pesticides. These included working with the Wisconsin Department of Conservation (which is the equivalent of the California Department Fish and Game) on projects devoted to rough fish control using toxaphene. Toxaphene is a chlorinated hydrocarbon pesticide that is highly toxic to fish. It was used for rough fish control in lakes where excessive numbers of carp had become the dominant fish species in the lake. Dr. Lee and his graduate students followed the fate of the toxaphene as it was applied to several Wisconsin lakes. They found that much of the toxaphene that was added to lakes for rough fish control was partially degraded after its addition to the lake, and, while there was a readily measurable residue in the lake sediments, extraction of this residue and its cleanup using

chromatographic procedures, showed that it was far less toxic than the parent materials added to the lake.

During the 1970s, Dr. Lee and his graduate students conducted over $1 million in research on developing dredged sediment disposal criteria, which included measuring organochlorine pesticides and PCBs at about 100 sites located across the US, where the Corps of Engineers conducted dredging and open-water disposal of dredged sediments from navigation channels. These studies specifically examined the release of OCls to the water column upon sediment suspension in a dredging operation. Further, during the 1970s, on behalf of the Corps of Engineers, Dr. Lee developed a comprehensive review of the water quality significance of PCBs in US waterway navigation channels as they might impact dredging and dredged sediment disposal.

Dr. Lee and his University of Wisconsin graduate students conducted several projects on organochlorine pesticide (aldrin and dieldrin) transport/fate in surface and ground waters. This was done as part of modeling the fate/transport of OCls in groundwater systems where they had been applied to crops for pest control.

Dr. Lee was an advisor to the Norfolk, Virginia, District of the Corps of Engineers on the dredging of the Intercoastal Waterway in the Virginia/North Carolina border area, where the concern was chlordane accumulation within the waterway sediments. This section of the Intercoastal Waterway had not been dredged for a number of years because of the report of excessive chlordane in the sediments. Dr. Lee showed that the analytical data for chlordane in these sediments were in error, due to improper methodology that was used in analyzing the sediments. Chlordane was not present in the sediments at potentially hazardous levels, which would affect the dredging project. Also, Dr. Lee was involved as an advisor during the 1970s to the San Francisco District of the Corps on dredging projects within San Francisco Bay, where excessive concentrations of organochlorine pesticides and PCBs were of concern, as they might impact dredging and dredged sediment disposal projects near Treasure Island.

Dr Lee's work on the water quality aspects of OCl pesticides and PCBs has been recognized by several national committees/organizations. In the early 1970s, Dr. Lee was an invited peer reviewer to the National Academies of Science and Engineering for the Blue Book of Water Quality Criteria. As a reviewer, he was responsible for conducting a review of the draft criteria that had been developed by the Academy committees, which included the OCl pesticides.

In the late 1970s, the Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi, issued a contract to Dr. Lee to develop a report addressing the technical issues it was facing in various parts of the US in which elevated levels of PCBs were being found during dredging for navigation channel maintenance. Dr. Lee then raised many of the same issues that are still unknown today with respect to the relationship between the concentrations of PCBs (and, for that matter, other OCls) in sediments and their uptake by fish to excessive levels in edible tissue. The same controversy exists today with respect to dredging of the Hudson River PCB-containing sediments, where the General Electric Company and its consultants have concluded that the current information available on the potential benefits of dredging Hudson River sediments as a means of lowering the PCB content of

striped bass in the Hudson River system is not adequate to support the US EPA's position that spending in excess of $30 million dredging selected locations in the Hudson River will significantly impact the PCB content of striped bass in the river.

He was asked by the US Public Health Service to chair a committee devoted to evaluating whether there was need for a PCB drinking water maximum contaminant level in order to protect the public from PCBs that were being found in domestic water supplies.

Dr. Lee served as an advisor to Monsanto Chemical Company on PCB issues. Further, he was interviewed by Walter Cronkite for CBS evening news on PCB pollution issues.

While teaching at the University of Wisconsin, Madison, Dr. Lee was appointed secretary for the Technical Advisory Committee for the Pesticide Review Board for the state. This committee advised the Pesticide Review Board on pesticide policy, which included recommending the banning of DDT from its further use in Wisconsin because of the adverse impacts of DDT on some bird populations. Dr. Lee was a member of the American Society for Testing and Materials Committee E-35, devoted to pesticides. He organized and chaired the Environmental Chemistry Fate Section of this committee for several years.

Dr. Lee conducted studies on the presence of PCBs and organochlorine pesticides in New York and New Jersey Harbor sediments, with particular reference to the potential bioaccumulation of these chemicals in aquatic organisms that inhabit the area of the Mud Dump site in the New York Bight. His studies of benthic organisms and benthic fish showed that, even though the sediments dredged from New York and New Jersey Harbors and dumped at the Mud Dump site in the New York Bight contained elevated concentrations of OCl pesticides and PCBs, these OCls were not being transferred to fish to produce excessive concentrations in fish tissue.

For several years, Dr. G. F. Lee was an advisor to the US EPA Region II in New York City, regarding the dredging of the Hudson River sediments for the purpose of lowering the PCB content of striped bass in the Hudson River and New York/New Jersey Harbors. While there were mathematical models which were claimed to link the PCB content of sediments to the PCB content of fish, they were deterministic models, which were not based on an understanding of the mechanism controlling the uptake of PCBs by striped bass from the sediments. It is possible that the sediment "hot spots," where the total concentrations of PCBs were greatly elevated, may not be the primary transfer point. The PCBs in those sediments are likely tightly bound, and, therefore, not as readily available for bio-uptake as the PCBs associated with sediments with a lower total PCB content and binding affinity for the sediments. These are issues that will be considered in the course of conducting a PCB/OCl pesticide remediation program.

In the early 1990s, Dr. Lee was part of an OEHHA invited group that conducted the comparative risk project for the State of California. One of the groups of chemicals that were considered in this project was the organochlorines as they may affect human health through consumption of fish that contain excessive concentrations of OCls.

During the early 1990s, when Dr. Lee served as a consultant to Simpson Paper Company, he was involved in reviewing the dioxin fate, transport and impacts associated with Simpson's Humbolt, California, mill, as well as the Anderson mill, which discharged its wastewaters to the Sacramento River. For a period of time, this mill's wastewater effluent contained dioxins at sufficient concentrations to cause many of the fish in the Sacramento River to contain excessive dioxins and furans.

Beginning in the mid-1990s, he became involved in a project in Orange County, California, in which there was concern about organochlorine pesticides and PCBs in Upper Newport Bay and its tributaries. As part of US EPA 205(j) and 319(h) projects, he conducted a comprehensive review of the information available on the OCls in these waters, sediments and aquatic life. He has recommended monitoring programs to the Santa Ana Regional Water Quality Control Board to fill information gaps on the current OCl status of fish and other aquatic life in Upper Newport Bay and its tributaries.

During the late 1990s through the present, Dr. Lee has been an advisor to the DeltaKeeper on pesticide issues within the Delta and its tributaries. This work has included advising on the water quality aspects of the organochlorine pesticides and PCBs.

Dr. Lee has been involved in litigation in the Salinas Valley concerning DDT transport from areas where strawberries are being grown. It has been found that the concentrations of DDT in stormwater runoff from these areas exceeded drinking water standards, which are well above those that would be expected to bioaccumulate to excessive levels in aquatic life.

Since 1989, when Dr. Lee retired from university teaching and research and moved to El Macero, near Davis, California, he has been active in Central Valley projects involving organochlorine pesticides and PCBs. He is a member of the Sacramento River Watershed Program and was instrumental in having this program include monitoring of fish tissue in the Sacramento River for organochlorines. This led to the finding that some fish in the Sacramento River have excessive concentrations of organochlorine pesticides and PCBs.

His work on OCl pesticides within the Central Valley has led to the situation where he was asked by the Central Valley Regional Water Quality Control Board staff to undertake the TMDL for control of excessive OCls in Central Valley fish.

In summary, Dr. Lee has a long history of working with the use, fate, transport and impacts of organochlorine pesticides and PCBs. He has published a number of refereed papers and reports devoted to the occurrence, transport, fate and impacts of organochlorines on public health and the environment. Additional information on his expertise and experience is available on his website, www.gfredlee.com

Supplemental Information on Dr. G. Fred Lee

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EDUCATION

Ph.D. Environmental Engineering & Environmental Science, Harvard University, Cambridge, Mass. 1960

M.S.P.H. Environmental Science-Environmental Chemistry, School of Public Health, University of North Carolina, Chapel Hill, NC 1957

B.A. Environmental Health Science, San Jose State University 1955

ACADEMIC AND PROFESSIONAL EXPERIENCE

Current Position:

Consultant, President, G. Fred Lee and Associates

Previous Positions:

Distinguished Professor, Civil and Environmental Engineering, New Jersey Institute of Technology, Newark, NJ 1984-89

Senior Consulting Engineer, EBASCO-Envirosphere, Lyndhurst, NJ (part-time) 1988-89

Coordinator, Estuarine and Marine Water Quality Management Program, NJ Marine Sciences Consortium Sea Grant Program 1986-1988

Director, Site Assessment and Remedial Action Division, Industry Cooperative Center for Research in Hazardous and Toxic Substances, New Jersey Institute of Technology et al., Newark, NJ 1984-1987

Professor, Department of Civil and Environmental Engineering, Texas Tech University 1982-1984

Professor, Environmental Engineering, Colorado State University 1978-1982

Professor, Environmental Engineering & Sciences; Director, Center of Environmental Studies, University of Texas at Dallas 1973-1978

Professor of Water Chemistry, Department of Civil & Environmental Engineering, University of Wisconsin-Madison 1961-1973

Registered Professional Engineer, State of Texas, Registration No. 39906

Dr. R. Scott Ogle, Pacific EcoRisk

For almost 17 years, Dr. Scott Ogle has been directing and/or participating in research in the areas of aquatic ecotoxicology and environmental chemistry. Dr. Ogle's major area of research includes evaluation of the fate and effects of metals, pesticides, and petroleum and petroleum products in aquatic ecosystems and the investigation of contaminants and toxicity in nonpoint source and stormwater runoff. Dr. Ogle has directed and participated in numerous projects encompassing all of the standardized US EPA and ASTM test procedures as well as projects involving development of new testing procedures. Much of Dr. Ogle's recent work has focused upon evaluation of contaminated freshwater, estuarine, and marine sediments.

Supplemental Information on Pacific EcoRisk – Dr. Scott Ogle

Lab Director, Pacific Eco-Risk Laboratories

EDUCATION:

Ph.D. Ecology (Aquatic Ecotoxicology)	1996
University of California, Davis, CA	
M.S. Water Science (Water Pollution Biology)	1988
University of California, Davis, CA	
B.S. Fisheries Biology (Water Quality)	1984
Humboldt State University, Arcata, CA	

PROFESSIONAL HISTORY:

PACIFIC ECO-RISK LABS, Martinez, CA	1994-Present
Principal and Laboratory Director	
S.R. HANSEN & ASSOCIATES, Concord, CA	1991-1994
Senior Scientist	
UNIVERSITY OF CALIFORNIA, Davis, CA	1991
Teaching Assistant (Fish Physiology)	
UNIVERSITY OF CALIFORNIA, Davis, CA	1986-1991
Research Assistant	
U.S. FISH & WILDLIFE SERVICE, Dixon, CA	1985
Biological Aide	

SCIENTIFIC/RESEARCH AWARDS:

1989-1990 Pre-Doctoral Fellow, Society of Environmental Toxicology and Chemistry

Best Student Presentation, SETAC, 9th Annual Meeting, 1988.

Jastro-Shields Graduate Research Award, 1986. University of California, Davis