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Technical Summary of Information Available on the Bioaccumulation of Arsenic in Aquatic Organisms

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NOTICE

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Glossary of Arsenic Abbreviations

As=	Arsenic
As(III)=	Arsenite
As(V)=	Arsenate
AsB=	Arsenobetaine
AsC=	Arsenocholine
TMA=	Trimethylarsine
DMA=	Dimethylarsenic acid
MMA=	Monomethylarsonic acid
TMAO=	Trimethylarsine oxide

1.0 INTRODUCTION

In 2000, the U.S. Environmental Protection Agency (EPA) published the *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health* (USEPA, 2000). That document (hereafter referred to as the 2000 Human Health Methodology) presents technical guidance and the procedure that EPA will follow when deriving new and revised national recommended ambient water quality criteria (AWQC) for the protection of human health under Section 304(a) of the Clean Water Act.

The 2000 Human Health Methodology incorporates a number of scientific advancements made over the past two decades. One of these advancements is in the assessment of chemical exposure to humans through the aquatic food web pathway. For certain chemicals, exposure via the aquatic food web is more important than exposure from ingestion of water. One method for incorporating chemical exposure to humans through the aquatic food web involves estimating the amount of a chemical expected to bioaccumulate in fish and shellfish that are commonly consumed by populations in the United States.

Previously, EPA primarily used bioconcentration factors (BCF) to estimate accumulation of waterborne chemicals by aquatic organisms. The BCF reflects contaminant accumulation by fish and shellfish only through the water column. Over the past two decades, however, science has shown that all the routes (e.g., food, sediment, and water) by which fish and shellfish are exposed to highly bioaccumulative chemicals may be important in determining the chemical accumulation in the organism's body, and that these chemicals can be transferred to humans when they consume contaminated fish and shellfish. The EPA's approach to estimating uptake into fish and shellfish now emphasizes the use of bioaccumulation factors (BAFs), which account for chemical accumulation from all potential exposure routes (USEPA 2000). The trophic level of fish and shellfish consumed by humans can be important in predicting human exposure through the consumption of contaminated fish and shellfish. Therefore, in EPA's 2000 Human Health Methodology national BAFs are estimated for trophic levels 2, 3, and 4 (BAF_2, BAF_3, and BAF_4, respectively), and are calculated as the geometric mean BAF of all species-specific BAFs calculated for a given trophic level (USEPA 2000).

This document contains a summary of information currently available on the bioaccumulation potential of arsenic in aquatic organisms. This information was gathered as a first step in assessing the quantity and quality of data available to derive national BAFs for updating the existing 304(a) human health ambient water quality criteria for arsenic. The Office of Science and Technology (OST) is performing this data review for arsenic because new scientific information has been developed regarding its bioaccumulation since the 304(a) criteria for arsenic was published in 1985 (USEPA 1985).

Information available that may be useful for determining bioaccumulation factors for arsenic is compiled in this document. National trophic-level specific BAFs are not included in this document because OST is in the process of determining if the data identified is sufficient to derive national BAFs. In the interim, we are making the results of the literature search available to States and authorized Tribes so that they have access to a current compilation and review of available data as they develop State and Tribal Water Quality Standards.

1.1 Important Bioaccumulation Concepts

Aquatic organisms accumulate and retain certain chemicals when exposed to these chemicals through water, their diet and other sources. The magnitude of accumulation can vary widely depending on the chemical and its properties. For chemicals that are persistent and hydrophobic, chemical concentrations in contaminated fish and shellfish may be several orders of magnitude higher than their concentrations in water. These chemicals may also biomagnify in aquatic food webs, a process whereby chemical concentrations increase in aquatic organisms of each successive trophic level due to increasing dietary exposures (e.g., increasing concentrations from algae, to zooplankton, to forage fish, to predator fish). For chemicals that biomagnify, consumption of contaminated fish and shellfish may pose unacceptable human health risks even when concentrations in water do not pose unacceptable health risks from consumption of water alone.

The term "bioaccumulation" refers to the net accumulation of a chemical by an aquatic organism as a result of uptake from all environmental sources (e.g., water, food, sediment). Bioaccumulation can be viewed as the result of competing rates of chemical uptake and elimination (chemical loss) by aquatic organisms. When the rates of chemical uptake and elimination achieve balance, the distribution of the chemical between the organism and its source(s) is said to be at steady-state. Under steady-state conditions, a BAF is the ratio (in L/kg) of the concentration of a chemical in the tissue of an aquatic organism to its concentration in water, in situations where both the organism and its food are exposed. (USEPA 2000). The BAF is calculated as:

$$BAF = \frac{C_t}{C_w} \qquad \text{(Equation 1)}$$

where:
C_t = concentration of the chemical in wet tissue (either whole organism or specified tissue)
C_w = concentration of chemical in water

1.2 Bioaccumulation of Arsenic

Arsenic, and/or its metabolites, is a chemical that bioaccumulates in tissues of aquatic organisms but does not biomagnify in the aquatic food chain (Chen and Folt 2000, Maeda et al. 1990, Mason et al. 2000, Spehar et al. 1980, Wagemann et al. 1978, Woolson 1975). Arsenic BAFs for upper trophic level freshwater and estuarine fish and shellfish typically consumed by humans generally range between 5 L/kg and 5,000 L/kg (Baker and King 1994, Cooper and Gillespie 2001, Chen et al. 2000, Chen and Folt 2000, Giusti and Zhang 2002, Langston 1984, Mason et al. 2000). Despite the recent attention focused on arsenic uptake and accumulation in aquatic biota, much uncertainty in the mechanisms and bioaccumulation potential of the various forms of arsenic in the environment still exists. The consensus in the literature is that upwards of 85% to >90% of arsenic found in edible portions of marine fish and shellfish is organic arsenic [arsenobetaine (AsB), arsenocholine (AsC), dimethylarsinic acid (DMA)] and that approximately 10% is inorganic arsenic (De Gieter et al. 2002, Goessler et al. 1997, Johnson and Roose 2002, Ochsenkuhn-Petropulu et al. 1997). Less is known about the forms of arsenic in freshwater fish, but there is evidence that organic arsenic may be as prevalent (Kaise et al. 1987; field-based study) or considerably less (Maeda et al. 1990, 1992, 1993; Suhendrayatna et al. 2001, 2002a,b; laboratory-based studies).

Knowledge about the uptake and methylation of arsenic by aquatic biota is important for estimating human health risk because it is becoming increasingly evident that methylation of arsenic is critical in controlling its biological fate and effects (Thomas et al. 2001). Inorganic arsenic was previously implicated as the primary toxic form to both aquatic life and humans (Spehar et al. 1980, USEPA 1985). More recent research indicates that when compared to arsenite, trivalent methylated arsenic metabolites[1] exert a number of unique biological effects, are more cytotoxic and genotoxic, and are more potent inhibitors of the activities of some enzymes (Kitchin and Ahmad 2003; Thomas et al. 2001). Because each arsenic species (e.g., As(III), As(V), AsB, MMA^{V}, MMA^{III}) exhibits different toxicities, it may be important to take into account the fraction of total arsenic present in the inorganic and organic forms when estimating the potential risk posed to human health through the consumption of arsenic-contaminated fish and shellfish. Ideally, the most appropriate BAFs for the protection of human health would incorporate the most bioavailable and toxic form(s). Although this may not be possible at this time, recent advances in analytical methodologies should eventually permit such assessment. Although very little organic arsenic is present in surface waters, and most arsenic found in groundwater and surface waters is inorganic in nature, the need still exists for information on as many relevant species of arsenic as possible. Specifically, for the derivation of AWQC, more data is needed on the chemical form and relative amounts of the various forms of arsenic in the tissues of aquatic organisms and in surface waters.

1.3 Overview of Document

This document is organized into three primary sections. Section 2.0 presents an overview of the literature search strategy, a discussion of data sources, the data quality parameters used to determine if data identified were appropriate for deriving BAFs, and the methods used to calculate BAFs from data found in the literature. The procedures for calculating the BAFs are those described in detail in the 2000 Human Health Methodology (USEPA 2000) and the Technical Support Document Volume 3: Development of National Bioaccumulation Factors (referred to hereafter as the Bioaccumulation TSD; USEPA, 2003). Section 3.0 contains summaries of experiments identified as having data acceptable and appropriate for deriving BAFs. Section 4.0 presents the data used to calculate an arsenic total/dissolved chemical translator. The chemical translator is used to convert arsenic BAFs from water concentration data reported as total arsenic. The translators are also necessary in the implementation of dissolved water quality standards where monitoring data are reported as total arsenic. Section 5.0 contains information regarding the relative fractions of inorganic and organic arsenic (e.g., As(III), As(V), AsB, AsC, DMA) in freshwater and estuarine/marine fishes and shellfish. A basic understanding of the relative fractions of the various arsenic forms in freshwater and saltwater organisms is useful for considering the representativeness and application of arsenic BAFs based on total arsenic. Finally, Section 6.0 contains a summary of BAFs for arsenic and the supporting chemical translator and tissue speciation data. All pertinent references are

[1] Primarily in the form of (mono)methylarsonous acid (MMA^{III}) and dimethylarsinous acid (DMA^{III}).

provided in Section 7.0. Appendix A contains the literature search strategy and data requirements. Appendix B contains an abbreviated summary of all the studies reviewed. Appendices C and D contain tables with the raw data calculations for each acceptable BCF (Appendix C) and BAF (Appendix D) study determined to be acceptable using the criteria outlined in Appendix A. Appendix E and F contain tables with the chemical translator and arsenic tissue speciation data, respectively, provided by ecosystem type and trophic level. Footnotes are provided in the tables where appropriate for clarification of data quality and data use in the BAF calculations.

2.0 LITERATURE SEARCH AND CALCULATION METHODS

2.1 Literature Search

A literature search strategy was designed to identify, to the extent possible, all data meeting the criteria for calculating BAFs using field or laboratory measurements. Preference was given to data published in the peer-reviewed literature. Data from publically available reports (e.g., State, Federal, or trade/industry group reports; dissertations; proceedings from professional meetings) were included if appropriate analytical techniques and quality assurance/quality control measures were provided. Studies identified in the literature search were reviewed within the context of deriving a national BAF and therefore the general data quality considerations described in EPA 2003 were used to judge the suitability of the data. Criteria used to determine the acceptability of field-measured BAFs and laboratory-measured BCFs are discussed in Section 5 of the 2000 Human Health Methodology (USEPA, 2000) and in Section 5 of the Bioaccumulation TSD (USEPA, 2003). The literature search strategy and data acceptability criteria are presented in Appendix A.

Every attempt was made to facilitate comparisons between studies. For example, arithmetic and geometric means were estimated, even if the original authors did not do so. Trophic levels for fishes were determined using EPA Guidance (USEPA 1995) and the information provided in the specific papers. When more than one BAF was estimated for a given species, a species-mean BAF (SBAF; calculated as the geometric mean) was calculated. There were, however, some exceptions to this general calculation procedure. In some cases where zooplankton data were available, each individual BAF was used to calculate the overall SBAF. This was done because a zooplankton sample consists of multiple species, with the composition varying from waterbody to waterbody. Also, in cases where species-mean BAFs were reported relative to fish age or size, each species mean age or size-specific BAF (e.g., caddis fly larva versus caddis fly pupa) is reported separately. In these instances, the age and size of the fish or shellfish species were taken into account for each trophic level designation.

Log normal distributions were assumed in this evaluation, partly for convenience, but primarily because the underlying process and factors that contribute to variability are likely to be multiplicative rather than additive. All species-mean BAFs reported in the summary tables have been rounded to two significant digits. For comparison purposes, BAFs reported in text discussions may be reported as calculated in the appendices. Because this compilation of data includes studies that used a variety of methods for measuring arsenic, statistical comparisons were not performed.

2.2 Methods for Estimating Bioaccumulation Factors

In the 2000 Human Health Methodology, EPA presents a framework for deriving BAFs for various types of chemicals (USEPA, 2000). For inorganics and organometallics, the national BAF methodology relies on field-measured BAFs and lab-measured BCFs without adjustments for site-specific factors that affect bioaccumulation (i.e., conversion to baseline BAF using lipid content of aquatic organisms and organic carbon concentrations in water is not necessary). The data provided in this report are provided on an individual study and species-mean basis and have not been translated into national trophic-level values at this time. Therefore the data provided may be applicable for derivation of BAFs for specific waterbodies, ecosystems, or regions. The applicability of the bioaccumulation presented in this report for site-specific use should be judged on a case-by-case basis.

For inorganic and organometallic chemicals, BAFs are calculated by one of two procedures, depending on whether or not the chemical undergoes biomagnification in aquatic food webs. Procedure 5 is recommended for inorganic and organometallic chemicals that do not biomagnify and Procedure 6 is recommended for chemicals that do biomagnify. For arsenic, biomagnification does not occur, therefore Procedure 5 is the recommended for deriving BAFs for arsenic. In Procedure 5, BAFs may be developed by two different methods, either from field-measured BAFs or from laboratory-measured BCFs. Because Procedure 5 applies only to chemicals that do not biomagnify, under this procedure BAFs and BCFs are considered to be of equal value in predicting BAFs and the use of food chain multipliers with BCF measurements is not required. A detailed discussion of the scientific basis for the BAF derivation methods and procedures used in the 2000 Human Health Methodology can be found in the Bioaccumulation TSD (2003).

BAFs estimated using data available from the field are calculated using the ratio of tissue and water arsenic data as shown in Equation 1 above. In Procedure #5, when appropriate field data does not exist, or if it is considered unreliable, BAFs for arsenic may be predicted from acceptable laboratory-measured BCFs. The general minimum criteria for overall data acceptability were as follows:

- measured levels of arsenic (or arsenical species) in whole body or edible tissue of aquatic organisms and in water;
- good analytical accuracy (standard recovery) and precision (reproducibility); and
- indication that steady-state was achieved (in the case of laboratory BCF studies).

The BAFs contained herein are all expressed on a wet-weight basis. BAFs reported or derived using measurements of arsenic on a dry-weight basis were converted using factors that were either measured or reliably estimated from the tissue used in the determination of the BAF. If no measured or reliable conversion factor was reported, zooplankton, shellfish, and other macroinvertebrates were assumed to be comprised of 80 percent water (multiplication factor = 0.2), and fish were assumed to be 75 percent water (multiplication factor = 0.25), in accordance with the *Mercury Report to Congress* (USEPA 1997).

According to the 2000 Human Health Methodology, data for total arsenic in edible tissue (i.e., muscle tissue) of fish and shellfish are preferred over whole body data since the general U.S. population doe not typically ingest the entire organism. The exception was for measurements of whole body arsenic in bivalves, aquatic insects and zooplankton. Although the general U.S. population does not commonly consume aquatic insects or zooplankton, available information on bioaccumulation of arsenic in these organism classes have been included in this report for comparison and for completeness.

In the few cases where it was possible (Baker and King 1994), and where the water exposure concentrations of arsenic were similar, total arsenic concentrations in whole body and edible tissues of the same species were compared. The results of this very preliminary assessment were inconclusive. Since no apparent differences were found in whole body versus edible tissue arsenic concentration, the species-mean BAF calculations were made using the tissue from which the majority of the BAFs were estimated for that ecosystem type and trophic level designation.

In this summary, only concentrations of total dissolved arsenic in water below levels that acutely affect aquatic organisms were used to derive BAFs. Acute arsenic (as As III) toxicity ranges from approximately 1,000 to 3,000 µg/L for amphipods and cladocerans to greater than 10,000 µg/L for most freshwater fishes. In saltwater, it ranges from approximately 250 µg/L for crabs and copepods to greater than 1,500 µg/L for bivalve molluscs, shrimps and fishes (USEPA 1985).

Using the methods outlined above, BAFs were calculated or predicted initially by trophic level for lakes (i.e., lentic aquatic systems), rivers (i.e., lotic aquatic systems), and estuaries. An ecosystem-approach to deriving BAFs was used because differences in general bioaccumulation trends would be expected among the aquatic ecosystems due to inherent differences in food web dynamics, arsenic loadings, and watershed interactions, among other factors. No clear differences in bioaccumulation trends were observed between lentic and lotic ecosystems based on qualitative and semi-quantitative comparisons of the data (see Section 3.5). The limited estuarine and marine data, however, do appear to indicate a possible need for deriving separate BAFs for saltwater systems.

3.0 BAFs FOR ARSENIC IN FRESHWATER AND SALTWATER ECOSYSTEMS

3.1 Estimation of BAFs Using Laboratory-measured BCFs

In this analysis, BAFs for trophic levels 2, 3, and 4 were predicted using the concentration of total arsenic in whole animal or muscle tissue and the concentration of arsenic in filtered (dissolved) laboratory water. Ten studies were identified as potentially useful for the derivation of a BAF from a laboratory-based BCF value. Five of the studies used saltwater (estuarine/marine) organisms, including three bivalve molluscs and a crustacean (Table 3-1). BCF determinations from the remaining five studies were conducted using several freshwater fish and invertebrate species. Studies by Gailer et al. (1995), Franseconi et al. (1999), Maeda et al. (1990, 1992, 1993), and Langston (1984) contain only one time period (#10 days) for which arsenic was measured in the organism (Table 3-1). Because steady-state conditions could not be confirmed in these studies, they were not considered acceptable for BAF determination. The study completed by Hunter et al. (1998) was not acceptable because the concentration of arsenic in exposure water was not measured. The study by Zaroogian and Hoffman (1982) using the eastern oyster, though it involved a 16 week flow-through exposure, was excluded because arsenic uptake by the oyster increased in the first 5 weeks, decreased with spawning, and increased again following spawing indicating that steady-state was never achieved. Perhaps more importantly, at least in the case of this latter study, statistical analysis showed arsenic uptake by oysters was not correlated with arsenic in seawater at the concentration range tested (3,000 to 5,000 µg/L), but was correlated with the arsenic concentration in the phytoplankton growing in the exposure tanks.

Spehar et al. (1980) report BCFs for four freshwater invertebrate species and for rainbow trout parr exposed for 28-days to arsenic [As(III)], arsenic [As(V)], sodium dimethyl arsenate (DMA), or disodium methyl arsenate (MMA). Although only total arsenic was measured in the test water, the turnover rates (100% water replacement in 9 hrs) were sufficiently high to maintain concentrations of the arsenical species provided (in the form of a salt). Target test concentrations for all experiments were 100 and 1,000 µg/L. Stoneflies, snails, and daphnids accumulated greater amounts of arsenic than fish. Arsenic tissue concentrations in treated rainbow trout were generally the same as those in control fish (approximately 0.75 µg/g wet weight). Amphipods did not accumulate arsenic above the detection limit of 5 µg/g when exposed to any of the arsenical compounds for 28 days. Arsenic accumulation in stoneflies and snails was generally higher (note: this is opposite of what is observed with field-measured BAFs, see Sections 3.2 and 3.3) when animals were exposed to higher concentrations and appeared to reach steady-state after 14 days. Total arsenic accumulation in stoneflies and snails exposed to 1,000 µg/L of the various arsenicals did not appear to be greatly affected by the form of arsenic in water, although some animals exposed to inorganic forms did exhibit higher tissue concentrations.

Mean BCFs for freshwater invertebrates (trophic level 2 species) ranged from 2 to 22 L/kg. For freshwater fish, mean BCFs ranged from 0.048 L/kg to 14 L/kg. These values are lower than those obtained for aquatic organisms from field studies (see Sections 3.2 and 3.3). No arsenic BCFs are available for saltwater fish species. BAFs predicted from laboratory BCF studies with saltwater invertebrates ranged from 12 L/kg to 1,390 L/kg. These too were generally lower on average than BAFs obtained for these species in field studies (Section 3.4).

Based on these data, it does not appear that water-only arsenic exposure fully represents environmental arsenic exposure. Therefore, the accuracy of using laboratory-measured BCFs to represent BAFs for arsenic should be carefully considered.

TABLE 3-1: BAFs for Arsenic in Aquatic Organisms Predicted from Laboratory-measured BCFs

BCF	Species	Duration	Method[a]	Arsenical Exposure	Reference
Freshwater					
9.0	Stonefly	28-d	FT, M	As(III)	Spehar et al. 1980
22	Cladoceran	28-d	FT, M	As(III)	Spehar et al. 1980
10	Snail	28-d	FT, M	As(III)	Spehar et al. 1980
5.0	Snail	28-d	FT, M	As(III)	Spehar et al. 1980
14	Rainbow trout	28-d	FT, M	As(III)	Spehar et al. 1980
4.0	Bluegill sunfish	28-d	FT, M	As(III)	Barrows et al. 1980
2.0	Zooplankter	7-d	S, U	As(V)	Maeda et al. 1990
14	Stonefly	28-d	FT, M	As(V)	Spehar et al. 1980
7.0	Cladoceran	28-d	FT, M	As(V)	Spehar et al. 1980
10	Snail	28-d	FT, M	As(V)	Spehar et al. 1980
8.0	Snail	28-d	FT, M	As(V)	Spehar et al. 1980
12	Red cherry shrimp	7-d	S, U	As(V)	Maeda et al. 1992
4.0	Guppy	7-d	S, U	As(V)	Maeda et al. 1990
0.048	Common carp	7-d	S, U	As(V)	Maeda et al. 1993
7.0	Stonefly	28-d	FT, M	MMA	Spehar et al. 1980
7.0	Cladoceran	28-d	FT, M	MMA	Spehar et al. 1980
5.0	Snail	28-d	FT, M	MMA	Spehar et al. 1980
3.0	Snail	28-d	FT, M	MMA	Spehar et al. 1980
6.0	Stonefly	28-d	FT, M	DMA	Spehar et al. 1980
9.0	Cladoceran	28-d	FT, M	DMA	Spehar et al. 1980
5.0	Snail	28-d	FT, M	DMA	Spehar et al. 1980
2.0	Snail	28-d	FT, M	DMA	Spehar et al. 1980

BCF	Species	Duration	Method[a]	Arsenical Exposure	Reference
Saltwater					
863	Eastern oyster	16 wk	FT, M	As(III)	Zaroogian and Hoffman 1982
12	Peppery furrow shell	10-d	R, M	As(V)	Langston 1984
1,390	Blue mussel	10-d	R, U	AsB	Gailer et al. 1995
1,300	Blue mussel	10-d	R, U	AsB	Franseconi et al. 1999
35	Common shrimp	24-d	R, M	AsB	Hunter and Goessler 1998
454	Blue mussel	10-d	R, U	AsC	Gailer et al. 1995
151	Blue mussel	10-d	R, U	TMAO	Gailer et al. 1995

[a] S= Static; FT = Flow-through; M = Measured; U = Unmeasured

3.2 Estimation of BAFs Using Field Data - Freshwater Lentic Ecosystems

3.2.1 BAFs for Trophic Level 2 Organisms

Wagemann et al. (1978) measured arsenic concentrations in several aquatic invertebrate species and in the ambient surface waters of lakes in the vicinity of Yellowknife, Northwest Territories, Canada. One of the lakes (Kam Lake) in the study received untreated sewage from the City of Yellowknife. This lake previously received seepages from two mine tailing ponds. A second lake for which data were available to calculate BAFs was Grace Lake. Grace Lake was chosen as a reference lake for the study because it was subject only to arsenic in the rock formations surrounding the Yellowknife District. Measured dissolved arsenic concentrations in the water of the two lakes for the year when the invertebrates were collected (1975) ranged from approximately 1.7×10^{-2} to 4.0×10^{-2} mg/L for Grace Lake (mean = 2.7×10^{-2} mg/L), and from 2.29 to 2.93 mg/L (mean = 2.58 mg/L) for Kam Lake. The invertebrates were collected in the littoral zone of each lake once every month during the summer (May to September 1975). The BAFs estimated for the various invertebrates sampled from Grace Lake (the designated reference lake) were consistently higher than the BAFs calculated for the same species in Kam Lake (the designated contaminated lake), see Table 3-2. The BAFs calculated for the invertebrates in Grace Lake were generally in the hundreds (range: 28.3 to 377.8 L/kg), while in Kam Lake, they were in the tens (range: 3.4 to 63.6 L/kg).

In a more recent study, Chen et al. (2000) examined the accumulation and fate of arsenic in numerous lakes and large and small zooplankton in the northeastern United States. Data were collected during August through October of 1995 and 1996. Each lake was sampled once for arsenic in water and plankton. Trace metal clean techniques were used for the collection and measurement of dissolved (0.45 µm filtration) arsenic in water. Plankton were collected with vertical tows in the deepest part of the lakes from 0.5 m above bottom to the surface using a cone net for macrozooplankton (> 202 µm size fraction; primarily adult copepods and cladocerans) and a Wisconsin net (45-202 µm size fraction) for large phytoplankton and small zooplankton. None of the lakes sampled were in watersheds with known point sources of metal pollution. The arsenic BAFs calculated for small zooplankton and large phytoplankton (range: 369 to 19,487

L/kg) were significantly higher than those calculated for larger zooplankton (range: 154 to 2,748 L/kg). Concentrations of total dissolved arsenic in the lakes ranged from 2.2 x 10^{-5} to 5.8 x 10^{-4} mg/L, whereas total arsenic in small and large zooplankton ranged from 0.0258 to 1.98 mg/kg, and from 0.0218 to 0.598 mg/kg, respectively. The authors determined that although the arsenic concentrations of the larger zooplankton were positively correlated with the dissolved arsenic concentration in water, they were best predicted by the arsenic levels in their diet (small zooplankton).

In a related study, Chen and Folt (2000) examined the trophic transfer of arsenic in a metal-contaminated lake on a seasonal basis. Using measurement and collection techniques similar to their earlier study (Chen et al. 2000), arsenic concentrations in water, particulates (phytoplankton; 0.4 to 0.45 µm), and the two different size fractions of zooplankton were measured in Upper Mystic Lake, New York in June, August and October 1997. Concentrations of dissolved arsenic in water peaked in August at approximately 1.11 x 10^{-3} mg/L, and were similar at around 6.0 x 10^{-4} mg/L in June and October (geometric mean of the three measurements = 7.81 x 10^{-4} mg/L). The arsenic concentrations in small zooplankton mirrored the fluctuating arsenic concentrations in water, while arsenic in larger zooplankton progressively increased from June through October, again indicating the potentially greater influence of dietary arsenic on the larger size class. The mean BAF for arsenic in small zooplankton from Upper Mystic Lake, NY was calculated as 4,391 L/kg; for large zooplankton, it was 2,747 L/kg (Table 3-2).

TABLE 3-2: BAFs for Arsenic in Trophic Level 2 Aquatic Organisms from Lentic Ecosystems

SBAF	BAF	Species	Location	Reference
9,400	9412	Small zooplankton	Canobie Lake, NY	Chen et al. 2000
560	560.9	Small zooplankton	Clear Pond, NY	Chen et al. 2000
770	768.4	Small zooplankton	Community Lake, NY	Chen et al. 2000
3,100	3084	Small zooplankton	Gregg Lake, NY	Chen et al. 2000
19,000	19,490	Small zooplankton	Horseshoe Pond, NY	Chen et al. 2000
390	385.0	Small zooplankton	Ingham Pond, NY	Chen et al. 2000
5,000	5008	Small zooplankton	Island Pond, NY	Chen et al. 2000
1,300	1285	Small zooplankton	Lake Placid, NY	Chen et al. 2000
630	630.6	Small zooplankton	Lower Kohanza Res., NY	Chen et al. 2000
500	503.7	Small zooplankton	Mirror Lake, NY	Chen et al. 2000
2,400	2,382	Small zooplankton	Palmer Pond, NY	Chen et al. 2000

SBAF	BAF	Species	Location	Reference
370	369.2	Small zooplankton	Post Pond, NY	Chen et al. 2000
1,700	1731	Small zooplankton	Queen Lake, NY	Chen et al. 2000
7,800	7,825	Small zooplankton	Tewksbury Pond, NY	Chen et al. 2000
7,600	7,623	Small zooplankton	Turkey Pond, NY	Chen et al. 2000
4,400	4,392	Small zooplankton	Upper Mystic Lake	Chen and Folt 2000
2,900	2,938	Small zooplankton	Williams Lake, NY	Chen et al. 2000
2,200	2,181	Large zooplankton	Canobie Lake, NY	Chen et al. 2000
190	192.9	Large zooplankton	Chaffin Pond, NY	Chen et al. 2000
1,200	1,174	Large zooplankton	Clear Pond, NY	Chen et al. 2000
150	153.7	Large zooplankton	Community Lake, NY	Chen et al. 2000
830	826.3	Large zooplankton	Gregg Lake, NY	Chen et al. 2000
1,300	1,344	Large zooplankton	Horseshoe Pond, NY	Chen et al. 2000
700	701.9	Large zooplankton	Ingham Pond, NY	Chen et al. 2000
590	590.2	Large zooplankton	Lake Placid, NY	Chen et al. 2000
390	390.6	Large zooplankton	Lower Kohanza Res., NY	Chen et al. 2000
270	274.3	Large zooplankton	Mirror Lake, NY	Chen et al. 2000
730	728.5	Large zooplankton	Post Pond, NY	Chen et al. 2000
570	573.8	Large zooplankton	Queen Lake, NY	Chen et al. 2000
580	578.9	Large zooplankton	Tewksbury Pond, NY	Chen et al. 2000
2,300	2,300	Large zooplankton	Turkey Pond, NY	Chen et al. 2000
2,700	2,748	Large zooplankton	Upper Mystic Lake	Chen and Folt 2000
960	962.5	Large zooplankton	Williams Lake, NY	Chen et al. 2000
200	197.8	Zooplankton	Grace Lake, NW Territories	Wagemann et al. 1978
55	55.0	Zooplankton	Kam Lake, NW Territories	Wagemann et al. 1978

SBAF	BAF	Species	Location	Reference
64	63.6	Oligochaeta	Kam Lake, NW Territories	Wagemann et al. 1978
34	109.6	Snail	Grace Lake, NW Territories	Wagemann et al. 1978
	10.3	Snail	Kam Lake, NW Territories	Wagemann et al. 1978
170	171.9	Bivalve mollusc	Grace Lake, NW Territories	Wagemann et al. 1978
110	107.4	Amphipoda	Grace Lake, NW Territories	Wagemann et al. 1978
380	377.8	Ephemeroptera	Grace Lake, NW Territories	Wagemann et al. 1978
21	105.9	Trichoptera	Grace Lake, NW Territories	Wagemann et al. 1978
	4.3	Trichoptera	Kam Lake, NW Territories	Wagemann et al. 1978
10	28.3	Corixidae	Grace Lake, NW Territories	Wagemann et al. 1978
	3.4	Corixidae	Kam Lake, NW Territories	Wagemann et al. 1978
47	229.6	Chironomidae	Grace Lake, NW Territories	Wagemann et al. 1978
	9.7	Chironomidae	Kam Lake, NW Territories	Wagemann et al. 1978

3.2.2 BAFs for Trophic Level 3 Organisms

The arsenic concentrations measured in aquatic invertebrates in Kam and Grace Lakes in the vicinity of Yellowknife, Northwest Territories, Canada by Wagemann et al. (1978) also included several predatory insects. As is noted above for the herbivorous insects, BAFs estimated for the predatory insects from Grace Lake (reference lake) were consistently higher than BAFs for the same species in the contaminated lake (Kam Lake). This is especially true for damselfly, where the difference between BAF estimates is greater than 250 fold (Table 3-3). In general, the difference in BAFs calculated for predatory insects and for sculpin fish exceeded 10 between the two lakes.

Chen and Folt (2000), in their examination of the trophic transfer of arsenic in Upper Mystic Lake, New York, also measured whole body arsenic accumulation in five different forage fish species: alewife, black crappie, bluegill sunfish, killifish, and yellow perch. Their objective was to compare the arsenic body burdens in fish with different feeding strategies and to determine whether arsenic burdens biodiminished[2] with respect to the various size classes of zooplankton. The fish were collected in October 1997 at multiple sites in the littoral zone of the lake using seines, fyke nets and minnow traps. Five individuals were obtained of each of the species for total arsenic analysis. The arsenic burdens for all fish in Upper Mystic Lake, NY

[2] Biodiminution is the trend of decreased chemical concentration in tissues of organisms as trophic level increases.

were 30 to 100 times lower than the burdens in zooplankton. Although the average concentrations in the various forage fish species differed by less than a factor of 2.5 (range from 0.031 mg/kg for black crappie to approximately 0.075 mg/kg for alewife), alewife and killifish (predominantly planktivorous fish species) had higher burdens than the bluegill sunfish, black crappie, yellow perch, which are higher on the trophic scale. Corresponding arsenic BAFs only ranged from 39.7 (black crappie) to 95.4 L/kg (alewife) - Table 3-3.

In a study to survey the upper Gila River, Arizona to determine if waters from mining and agricultural drainages had the potential to cause significant harmful effects on fish and wildlife, Baker and King (1994) measured the total arsenic concentrations in water and fish from San Carlos Reservoir and Talkalai Lake. Three unfiltered water samples were collected from each site from June to August 1990 for measurement of total recoverable arsenic, along with five-specimen whole-body or edible portion composites of near equal weight or length of each forage fish species that was collected (i.e., channel catfish and common carp). The total recoverable arsenic concentrations in water were the same for both the San Carlos Reservoir and Talkalai Lake at 8.0 x 10^{-3} mg/L. This is equivalent to 6.7 x 10^{-3} mg/L dissolved arsenic using the default chemical translator of 0.84 to convert to a dissolved arsenic value as described in Section 4.0 of this document. Whole body and fillet samples contained similar levels of arsenic for each fish species at approximately 1.0 to 2.0 x 10^{-1} mg/kg. Corresponding BAFs based on the estimated concentration of arsenic dissolved in San Carlos Reservoir and in whole body samples of channel catfish and carp were 29.76 and 14.88 L/kg, respectively (Table 3-3). The BAF calculated for carp in Talkalai Lake was 29.76 L/kg.

Skinner (1985) conducted a preliminary study at several electric utility wastewater treatment basins to determine if fish caught from these treatment basins presented a risk to human health through their consumption. Nine basins were sampled October 6–9, 1983 using shore zone electroshocking and seining and open-water trawling at various depths. Fish species common to the basins and representing bottom feeders and predators were targeted. Edible portions (fillets) of specimens of legal or recreationally sought sizes were prepared and analyzed for total arsenic concentration. Corresponding water samples from near mid-basin and from approximately 25 cm below the surface were also collected from each basin from where fish were taken. Concentrations of total arsenic in water from the various basins ranged from 3.0 x 10^{-3} to 3.0 x 10^{-2} mg/L total arsenic, or from 2.52 x 10^{-3} to 2.5 x 10^{-2} mg/L dissolved arsenic using the default arsenic chemical translator of 0.84 (see Section 4.0). Arsenic in muscle tissue from opportunistic bottom feeders in the basins (brown bullhead, common carp, channel catfish) ranged from <0.04 to 0.18 mg/kg wet weight (assuming a water content of 80% as used by the author in the article), and from <0.04 to <0.10 mg/kg wet weight for other forage fish species (e.g., black crappie, pumpkinseed). Since most of the arsenic in fish tissue was below the level of detection, only BAFs for carp collected from the various basins could be calculated. Arsenic accumulation in carp muscle tissue did not appear to be related to the concentration of total arsenic in water. For example, whole body arsenic in carp from Brunner Island Wastewater Treatment Pond #6 (6.0 x 10^{-2} mg/kg) was quite low despite the relatively high dissolved arsenic concentration in water estimated for that basin (2.5 x 10^{-2} mg/L). BAFs for carp from the electric utility wastewater treatment basins ranged from 2.38 to 71.4 L/kg (Table 3-3).

To summarize, species- mean BAFs (SBAFs) for eight species of forage fish and 10 different predatory insects and a carnivorous leech (Hirudinea) were available from four different studies (Baker and King 1994, Chen and Folt 2000, Skinner 1985, Wagemann et al. 1978). In general, those fish species that are lower on the trophic scale (alewife, killifish) had higher BAFs than those species that are slightly higher on the trophic scale (perch, crappie, catfish, carp, sunfishes). In contrast, data from Moon Lake, Mississippi reported in Cooper and Gillespie (2001) show the average concentration of total arsenic in omnivorous fish species (BAF = 6.0 L/kg) to be twice as high as in benthivorous fishes (BAF = 2.7 L/kg), and nearly 20 times higher than planktivorous fishes (BAF = 0.2 L/kg). The species-mean BAFs for trophic level 3 fish in lakes only range by a factor of 5, from approximately 19 to 96 L/kg. By comparison, the species-mean BAFs for trophic level 3 aquatic insects range from approximately 1 to 26 L/kg.

TABLE 3-3: BAFs for Arsenic in Trophic Level 3 Aquatic Organisms from Lentic Ecosystems

SBAF	BAF	Species	Location	Reference
17	20.1	leech	Grace Lake, NW Territories	Wagemann et al. 1978
	14.7	leech	Kam Lake, NW Territories	Wagemann et al. 1978
17	68.3	dragonfly	Grace Lake, NW Territories	Wagemann et al. 1978
	4.5	dragonfly	Kam Lake, NW Territories	Wagemann et al. 1978
31	40.9	damselfly	Grace Lake, NW Territories	Wagemann et al. 1978
	0.2	damselfly	Kam Lake, NW Territories	Wagemann et al. 1978
4.7	19.2	whirligig beetles	Grace Lake, NW Territories	Wagemann et al. 1978
	1.1	whirligig beetles	Kam Lake, NW Territories	Wagemann et al. 1978
13	13.3	water strider	Grace Lake, NW Territories	Wagemann et al. 1978
7.4	23.6	back swimmer	Grace Lake, NW Territories	Wagemann et al. 1978
	2.3	back swimmer	Kam Lake, NW Territories	Wagemann et al. 1978
11	48.1	diving beetle	Grace Lake, NW Territories	Wagemann et al. 1978
	2.5	diving beetle	Kam Lake, NW Territories	Wagemann et al. 1978
4.0	4.0	water mite	Kam Lake, NW Territories	Wagemann et al. 1978
4.9	25.9	ceraptogonid	Grace Lake, NW Territories	Wagemann et al. 1978
	0.9	ceraptogonid	Kam Lake, NW Territories	Wagemann et al. 1978
3.1	3.1	tanypodinae	Kam Lake, NW Territories	Wagemann et al. 1978

SBAF	BAF	Species	Location	Reference
		midge		
19	2.38[a]	common carp	Brunner Is. WTB #6	Skinner 1985
	19.84[a]	common carp	Martins Cr. IWTB	Skinner 1985
	27.78[a]	common carp	Martins Cr. IWTB	Skinner 1985
	19.84[a]	common carp	Martins Cr. IWTB	Skinner 1985
	71.43[a]	common carp	Montour Detention Basin	Skinner 1985
	63.49[a]	common carp	Montour Detention Basin	Skinner 1985
	15.87[a]	common carp	Montour Stormwater Basin	Skinner 1985
	15.87[a]	common carp	Montour Stormwater Basin	Skinner 1985
	10.42[a]	common carp	Montour Fly Ash Basin	Skinner 1985
	14.88[a]	common carp	San Carlos Reservoir, AZ	Baker and King 1994
	29.76[a]	common carp	Talkalai Lake, AZ	Baker and King 1994
95	95.4	alewife	Upper Mystic Lake	Chen and Folt 2000
30	29.76[a,b]	channel catfish	San Carlos Reservoir, AZ	Baker and King 1994
	14.88[a,c]	channel catfish	San Carlos Reservoir, AZ	Baker and King 1994
86	85.8	killifish	Upper Mystic Lake	Chen and Folt 2000
40	39.7	black crappie	Upper Mystic Lake	Chen and Folt 2000
48	47.7	bluegill sunfish	Upper Mystic Lake	Chen and Folt 2000
59	58.6	yellow perch	Upper Mystic Lake	Chen et al. 2000
29	70.6	sculpin	Grace Lake, NW Territories	Wagemann et al. 1978
	11.8	sculpin	Kam Lake, NW Territories	Wagemann et al. 1978

[a]Value adjusted using arsenic chemical translator of 0.84 to normalize to a BAF based on dissolved arsenic in water.
[b]Based on whole body value; only this value was used in the calculation to determine the SBAF for the species.
[c]Based on edible tissue.

3.2.3 BAFs for Trophic Level 4 Organisms

In addition to the several forage fishes which were examined to assess the trophic transfer of arsenic in metal-contaminated Upper Mystic Lake, New York, Chen and Folt (2000) also measured whole body arsenic accumulation in the largemouth bass. Five individuals were obtained for total arsenic analysis in October 1997. The mean concentration of dissolved arsenic in water measured in June, August and October 1997 was 7.81×10^{-4} mg/L. The average arsenic burden for largemouth bass in Upper Mystic Lake, NY (3.6×10^{-2} mg/kg) was approximately 60 to 95 times lower than the burdens in large and small zooplankton, respectively. The average arsenic concentrations in largemouth bass differed by less than a factor of 2 from the various forage fishes it preys upon, and had an arsenic BAF of 46.1 L/kg (Table 3-4).

In the study of the Upper Gila River, Arizona reported by Baker and King (1994), the BAF for largemouth bass based on whole-body tissue was very similar to the value derived for this species by Chen and Folt (2000). The BAF for largemouth bass in San Carlos Reservoir, AZ (in the Upper Gila River Watershed), was based on the estimated dissolved arsenic concentration in the reservoir ($0.84 \times 8.0 \times 10^{-3}$ mg/L or 6.72×10^{-3} mg/L) and the total arsenic concentration in a composite of 5 individuals. Analysis of whole body and fillet samples of these bass indicated slightly different levels of total arsenic: 3.0×10^{-1} and 1.0×10^{-1} mg/kg, respectively. As a result, the corresponding BAFs for whole body and edible tissue were 44.64 and 14.88 L/kg, respectively (Table 3-4). Only the BAF based on the whole body arsenic concentration was used to calculate the BAFs for this species because too few BAFs based on edible fish tissue for these and other fish species exist to warrant otherwise.

TABLE 3-4: BAFs for Arsenic in Trophic Level 4 Fish from Lentic Ecosystems

SBAF	BAF	Species	Location	Reference
45	44.64[a,b]	largemouth bass	San Carlos Reservoir, AZ	Baker and King 1994
	14.88[a,c]	largemouth bass	San Carlos Reservoir, AZ	Baker and King 1994
	46.1	largemouth bass	Upper Mystic Lake	Chen and Folt 2000

[a]Value adjusted using arsenic chemical translator of 0.84 to normalize to a BAF based on dissolved arsenic in water.
[b]Based on whole body value; only this value was used in the calculation to determine the SBAF for the species.
[c]Based on edible tissue.

3.3 Estimation of BAFs Using Field Data - Freshwater Lotic Ecosystems

3.3.1 BAFs for Trophic Level 2 Organisms

Only two studies were found for calculating BAFs for trophic level 2 aquatic organisms in lotic ecosystems. Mason et al. (2000) sampled herbivorous insects and other aquatic organisms in October 1997, April 1998, and July 1998 from two sites in western Maryland: Harrington Creek Tributary and Blacklick Run. Water samples (filtered *in situ* at 0.8 µm) were collected monthly in both of the streams using clean techniques. The average dissolved arsenic concentrations in water were 6.7×10^{-4} and 3.7×10^{-4} mg/L for Harrington Creek and Blacklick Run, respectively. Despite the difference in dissolved arsenic concentrations, there was no concomitant variation in insect arsenic burdens between the two sites. BAFs for herbivorous aquatic insects were consistently highest in Blacklick Run (Table 3-5). The authors also noted a trend of increasing arsenic body burden with decreasing average size of the animal, which they ascribed to the dependence of arsenic accumulation in small insects on the surface/volume ratio during the process of adsorption directly from water. A similar phenomenon was observed in studies by Hare et al. (1991) and Cain et al. (1992).

In addition to the BAF data available from Herrington Creek and Blacklick Run, arsenic levels present in arsenic-rich river water and biota collected from the Haya-kawa River at hot springs in Hakone, Kanagawa, Japan are available in Kaise et al. (1997). In this study, the aquatic herbivorous insects collected included a freshwater snail (*Semisulcospira libertina*) and the larvae and pupae of a caddisfly (*Stenopsyche marmorata*). The river water at the site where the insects were collected contained 3.0×10^{-2} mg/L total arsenic, 93% of which was inorganic and the remaining 7% trimethylated arsenic. The concentration of total arsenic in caddisfly pupae was substantially higher (2.05 mg/kg) than in the larvae of this species (2.36×10^{-1} mg/kg) and in the marsh snails (1.86×10^{-1} mg/kg). BAFs based on estimated concentration of dissolved arsenic in Haya-kawa River water ($0.84 \times 3.0 \times 10^{-2}$ mg/L or 2.52×10^{-2} mg/L) were less than 10 L/kg for caddisfly larvae and marsh snails, and approximately 81 L/kg for caddifly pupa (Table 3-5).

TABLE 3-5: BAFs for Arsenic in Trophic Level 2 Aquatic Organisms from Lotic Ecosystems

SBAF	BAF	Species	Location	Reference
7.4	7.38[a]	snail (marsh)	Hayakawa River, Japan	Kaise et al. 1997
3,800	5,619	mayfly	Blacklick Run, MD	Mason et al. 2000
	2,543	mayfly	Herrington Creek, MD	Mason et al. 2000
600	604.6	shredder stonefly	Blacklick Run, MD	Mason et al. 2000
2,300	2,810	caddisfly	Blacklick Run, MD	Mason et al. 2000
	1,846	caddisfly	Herrington Creek, MD	Mason et al. 2000
9.4	9.37[a,b]	caddisfly (larva)	Hayakawa River, Japan	Kaise et al. 1997
81	81.35[a,b]	caddisfly (pupa)	Hayakawa River, Japan	Kaise et al. 1997
970	2,401	cranefly	Blacklick Run, MD	Mason et al. 2000
	392.8	cranefly	Herrington Creek, MD	Mason et al. 2000

[a]Value adjusted using arsenic chemical translator of 0.84 to normalize to a BAF based on dissolved arsenic in water.
[b]Values shown to indicate the gross differences in bioaccumulation between the various life stages of this species. Most data for aquatic insects in this document are for larvae of the species; pupa were rarely measured.

3.3.2 BAFs for Trophic Level 3 Organisms

Both Mason et al. (2000) and Kaise et al. (1997) included several other aquatic organisms in their studies, including a number of forage fishes, freshwater crustaceans, and some predatory aquatic insects (Table 3-6). Added to this compilation are BAFs for channel catfish, flathead catfish, and common carp from numerous sites along the Gila and San Francisco Rivers, AZ (Baker and King 1994). BAFs for trophic level 3 organisms from the more polluted Haya-kawa, Gila, and San Francisco Rivers are consistently lower, generally by more than an order of magnitude or more, compared to like organisms in the western Maryland streams, Harrington Creek and Blacklick Run, respectively (Table 3-6). The highest BAFs were for dobsonflies, dragonflies and predatory stoneflies (Family: *Perlidae*), and the lowest for several of the forage fishes, particularly the sweet fish, Japanese dace, and mottled sculpin.

TABLE 3-6: BAFs for Arsenic in Trophic Level 3 Aquatic Organisms from Lotic Ecosystems

SBAF	BAF	Species	Location	Reference
32	32.42[a]	prawn	Hayakawa River, Japan	Kaise et al. 1997
560	489.2	crayfish	Blacklick Run, MD	Mason et al. 2000
	646.4	crayfish	Herrington Creek, MD	Mason et al. 2000
1,000	1,333.5	predatory stonefly	Blacklick Run, MD	Mason et al. 2000
	824.8	predatory stonefly	Herrington Creek, MD	Mason et al. 2000
500	195.7	dragonfly	Blacklick Run, MD	Mason et al. 2000
	1257	dragonfly	Herrington Creek, MD	Mason et al. 2000
690	1102	dobsonfly	Blacklick Run, MD	Mason et al. 2000
	432.1	dobsonfly	Herrington Creek, MD	Mason et al. 2000
110	114.1[a]	dobsonfly larva	Hayakawa River, Japan	Kaise et al. 1997
420	571.1	brook trout (small)	Blacklick Run, MD	Mason et al. 2000
	308.2	brook trout (small)	Herrington Creek, MD	Mason et al. 2000
2.0	2.02[a]	sweet fish	Hayakawa River, Japan	Kaise et al. 1997
8.5	10.82[a]	common carp	Gila River, AZ	Baker and King 1994
	11.90[a]	common carp	Gila River, AZ	Baker and King 1994
	4.76[a]	common carp	Gila River, AZ	Baker and King 1994
11	10.60[a]	downstream	Hayakawa River, Japan	Kaise et al. 1997

SBAF	BAF	Species	Location	Reference
		fatminnow		
510	512.7	blacknose dace	Blacklick Run, MD	Mason et al. 2000
280	281.5	creek chub	Herrington Creek, MD	Mason et al. 2000
4.0	3.97	Japanese dace	Hayakawa River, Japan	Kaise et al. 1997
380	376.1	white sucker	Herrington Creek, MD	Mason et al. 2000
280	283.9	brown bullhead	Herrington Creek, MD	Mason et al. 2000
5.3	7.00[a]	channel catfish	Gila River, AZ	Baker and King 1994
	3.50[a]	channel catfish	Gila River, AZ	Baker and King 1994
	5.95[a]	channel catfish	San Francisco River, AZ	Baker and King 1994
6.5	3.50[a]	flathead catfish	Gila River, AZ	Baker and King. 1994
	7.00[a]	flathead catfish	Gila River, AZ	Baker and King. 1994
	11.90[a]	flathead catfish	Gila River, AZ	Baker and King. 1994
	11.90[a,b]	flathead catfish	Gila River, AZ	Baker and King. 1994
	5.95[a]	flathead catfish	San Francisco River, AZ	Baker and King 1994
15	14.68[a]	amphidromous goby	Hayakawa River, Japan	Kaise et al. 1997
13	13.21	goby	Hayakawa River, Japan	Kaise et al. 1997
800	798.1	Mottled Sculpin	Blacklick Run, MD	Mason et al. 2000

[a]Value adjusted using arsenic chemical translator of 0.84 to normalize to a BAF based on dissolved arsenic in water.
[b]Value was based on edible tissue, and therefore, was not used in calculation of the SBAF in lieu of several based on whole body values.

3.3.3 BAFs for Trophic Level 4 Organisms

BAFs are only available for two coldwater trophic level 4 fish species in lotic ecosystems, large brook trout (from Mason et al. 2000) and masu salmon (Kaise et al. 1997). As noted above, BAFs for brook trout from the less arsenic contaminated streams in western Maryland (Herrington Creek and Blacklick Run) were substantially higher than the BAF estimated for masu salmon collected from the arsenic-rich Haya-kawa River, Japan (Table 3-7). The SBAF for brook trout was calculated to be 270 L/kg, while for masu salmon it was 45 times lower at 5.8 L/kg (Table 3-7). Compared to the BAFs estimated for forage fishes and other trophic level 3 aquatic organisms from the same locations (refer to Table 3-6 above), the BAFs for the trophic level 4 fishes were approximately the same.

TABLE 3-7: BAFs for Arsenic in Trophic Level 4 Fish from Lotic Ecosystems

SBAF	BAF	Species	Location	Reference
270	304.6	brook trout (large)	Blacklick Run, MD	Mason et al. 2000
	237.8	brook trout (large)	Herrington Creek, MD	Mason et al. 2000
5.8	5.79[a]	masu salmon	Hayakawa River, Japan	Kaise et al. 1997

[a]Value adjusted using arsenic chemical translator of 0.84 to normalize to a BAF based on dissolved arsenic in water.

3.4 Estimation of BAFs for Arsenic Using Field Data - Saltwater Ecosystems

3.4.1 BAFs for Trophic Level 2 Organisms

Three studies contain information useful for calculating BAFs for trophic level 2 saltwater organisms (Giusti and Zhang 2002, Langston 1984, and Valette-Silver et al. 1999). All three studies examined the arsenic burdens in edible tissues of bivalve molluscs, and included the measured dissolved arsenic concentration in the exposure water. A fourth study by Hung et al. (2001) reportedly contains information on the arsenic burdens in over 30 different marine molluscs at over 12 different coastal sites in Taiwan, but the species-specific values for arsenic in tissue were not provided in the condensed summary of information included in the published article.

Giusti and Zhang (2002) examined the level of trace element contamination in water, sediment and the marine mussel *Mytilus galloprovincialis* in a section of the Venice Lagoon near Murano Island, Italy. The dissolved, labile arsenic concentration in the water of the lagoon was measured by means of a recently developed trace metal speciation technique referred to as DGT (diffusive gradients in thin-films). The DGT technique allows trace metal speciation measurements to be made *in situ* in marine and fresh waters. In this study, two DGT devices were deployed together at each site to determine the arsenic concentrations representative of the dissolved fraction of arsenic in water available to the mussels. Mussels from about 3–7 cm long were collected from wooden pillars at the four sites where they were most common. They were depurated for 24-h in water from a reference site prior to separating soft tissue from the shells. The soft tissues from all organisms from a site were pooled prior to measuring the total arsenic concentration. Arsenic burdens in the mussels ranged from 2.4 to 3.6 mg/kg. Dissolved, labile arsenic in water from the corresponding sites ranged from 1.90×10^{-3} mg/L to 4.73×10^{-3} mg/L. BAFs were from 762 to 1263 L/kg (Table 3-7).

Valette-Silver et al. (1999) examined the arsenic concentrations in bivalve samples collected under the National Status and Trends Program (NS&T), Mussel Watch Project (MWP) from the southeast coasts of the U.S. Compared to the rest of the U.S., the oysters collected from sites located along the southeastern coasts, from North Carolina to the Florida panhandle, displayed high concentrations of arsenic in their soft tissues. As part of their examination of this phenomenon in oysters, samples of two species of bivalves (the eastern oyster and a marine mussel species - *Isognomon* sp.), water, sediment, and particulates, were collected in 1993 in

Biscayne Bay, Florida in addition to the samples collected in the NS&T MWP. In the brackish waters collected from the mouth of the Miami River feeding into Biscayne Bay, total dissolved arsenic concentrations averaged 8.9 x 10^{-4} mg/L. Most of the arsenic in the water was present as inorganic arsenate (As(V) = 6.9 x 10^{-4} mg/L versus As(III) = 1.0 x 10^{-4} mg/L), with only very small concentrations of organic arsenic present (MMA = 3.0 x 10^{-5} mg/L and DMA = 6.0 x 10^{-5} mg/L). The average total arsenic concentration in eight individual mussels was high at 7.46 mg/kg, while the total arsenic in small oysters averaged 4.72 mg/kg. The corresponding BAFs calculated for the two bivalve species are 8,382 L/kg and 5,303 L/kg, respectively (Table 3-7).

Langston et al. (1984) carried out a field and laboratory evaluation of the availability of arsenic to estuarine and marine organisms. The field study area focused primarily on Restronguet Creek, a branch of the Fal estuary system. Restronguet Creek has historically been contaminated by metalliferous mining in southwest England. Water, sediment, and selected organisms were collected from Restrognuet Creek between 1978 and 1981, and for comparison, from the Tamar and Torridge estuaries. The accumulation of arsenic in the field was studied by transplanting the bivalve mollusc *Scrobicularia plana* from the Tamar estuary to sites in Restrognuet Creek and recovering subsamples (usually 6 individuals were pooled for analysis) at intervals between February 1980 and March 1981. The effect of dissolved arsenic concentration on uptake rate in the laboratory was also determined in Tamar *S. plana* (3 cm shell length) using ^{74}As as arsenic acid. Arsenic concentrations in *S. plana* transferred from the Tamar estuary to site S in Restrognuet Creek (4.9 x 10^{-3} mg/L measured dissolved arsenic concentration taken at high-water, 4 September 1980) had more than doubled in 1 month and after 4 months were similar to levels in native individuals (approximately 32 mg/kg, whole bivalve). The arsenic concentrations in native and transplanted populations remained constant for the remainder of the experiment (up to 12 months). The total arsenic in tissue remained stable despite a seasonal increase in concentrations of dissolved arsenic entering the creek during the summer. This observation suggested to the authors a particulate (dietary) rather than waterborne source of arsenic for this mollusc species, which was confirmed through laboratory studies where concentration factors determined for this species in experimental exposures to dissolved arsenic were two orders of magnitude less than the estimated values in natural populations. The BAF for transplanted *S. plana* in Restroguet Creek was estimated to be 6,490 L/kg (Table 3-7). Additional BAFs for native populations of this species in Restrognuet Creek and the Tamar Estuary based on measured interstitial water arsenic concentrations and tissue concentrations back-calculated from the reported concentration factors at the sites are 776.8 L/kg and 623.9 L/kg, respectively (Table 3-7). The latter values were not included in the calculation of the SBAF for the species.

TABLE 3-8: BAFs for Arsenic in Trophic Level 2 Aquatic Organisms from Saltwater Ecosystems

SBAF	BAF	Species	Location	Reference
6,500	6,490	bivalve	Restronguet Cr., Fal Estuary, U.K.	Langston 1984
	776.8[a]	bivalve	Restronguet Cr., Fal Estuary, U.K.	Langston 1984
	623.9[a]	bivalve	Tamar Estuary, U.K.	Langston 1984

880	1,263	mussel	Is. of Murano, Italy - Site G	Giusti and Zhang 2002
	680.8	mussel	Is. of Murano, Italy - Site E	Giusti and Zhang 2002
	923.1	mussel	Is. of Murano, Italy - Site B	Giusti and Zhang 2002
	761.6	mussel	Is. of Murano, Italy - Site F	Giusti and Zhang 2002
8,400	8,382	mussel	Biscayne Bay, FL	Valette-Silver et al. 1999
5,300	5303	oysters	Biscayne Bay, FL	Valette-Silver et al. 1999

[a]Value was based on measurements of arsenic in interstitial water, and therefore, was not used in calculation of the SBAF in lieu of a value based on measurements of total dissolved arsenic in the water column.

3.5 Summary of BAFs for Arsenic in Freshwater and Saltwater Ecosystems

Preliminary assessment of BAFs estimated from laboratory-measured BCFs indicate that the estimated values are lower than those derived using data from the field BAFs. Much of the BCF data failed to meet the requirement that steady-state conditions be achieved during the exposure.

The majority of the BAFs estimated for trophic level 2 organisms in lentic ecosystems come from a single comprehensive study of arsenic accumulation in northeastern lakes (Chen et al. 2000). Although the lakes are free from any known point sources of arsenic, the range in species-mean BAFs is quite large, and highest for the smaller size class of zooplankton collected. Other values were estimated from trophic level 2 aquatic insects from the Northwest Territories, Canada (Wagemann et al. 1978). The species-mean BAFs estimated for these species are substantially lower on the average than for the zooplankters, though mostly higher than those estimated for organisms comprising the higher trophic levels (3 and 4, respectively). Only one species-mean BAF is available for trophic level 4 organisms.

The BAFs estimated for trophic level 2 organisms in lotic ecosystems are all for herbivorous aquatic insects from one of three river systems, Haya-kawa River, Japan (Kaise et al. 1997), and Harrington Creek and Blacklick Run tributaries in northwest Maryland (Mason et al. 2000). Trophic level 3 and 4 species-mean BAFs for lotic ecosystems were more variable than those for lentic ecosystems (Table 3-8). There is no clear explanation for this finding. The number and diversity of aquatic organisms represented at these higher trophic levels were about the same. Moreover, the concentrations of total and dissolved arsenic in water from the various lakes represented were more variable than for rivers and streams.

An observation that does seem to hold for both lentic and lotic ecosystems is that BAFs estimated for aquatic animals in the most arsenic contaminated waters were consistently lowest. This phenomenon has been noted for other trace elements, most recently for selenium (McIntyre et al. 2002). However, unlike arsenic, selenium is considered an essential trace metal.

The concentrations of arsenic in the edible soft tissues of marine and estuarine bivalve mollusks are substantially higher than for their freshwater counterparts. Species-mean BAFs were calculated for four saltwater species, from three different studies. In one study (Lin, 2001) arsenic BAF data for the herbivorous marine fish species the mullet, *Liza macrolepis,* was over several hundred times lower than the lowest BAF estimated for a saltwater species.

TABLE 3-9: Summary of BAFs for Arsenic by Trophic Level for Freshwater and Saltwater Ecosystems

Trophic Level	Freshwater Species-Mean BAFs Range (number)		Saltwater Species-Mean BAFs Range (number)
	Lentic	Lotic	
2	9.8 - 19,000 (n = 43)	7.4 - 3,800 (n = 7)	880 - 8,400 (n = 4)
3	4.0 - 95 (n = 18)	(2.0 - 1,000) (n = 20)	-
4	45 - 46 (n =1)	5.8 - 270 (n =2)	-

4.0 CHEMICAL TRANSLATOR FOR ARSENIC IN SURFACE WATERS

4.1 Introduction to Chemical Translators

Dissolved forms of a chemical are more readily bioaccumulated by organisms than are corresponding particulate forms. Dissolved metal more closely approximates the bioavailable fraction of metal in the water column than does total recoverable metal (USEPA 1993). This does not necessarily mean that particulate metal is nontoxic, only that particulate metal uptake into aquatic organisms is limited (USEPA 1996). Dissolved metal is *operationally defined* as that which passes through a 0.45 µm or a 0.40 µm filter and particulate metal is *operationally defined* as total recoverable metal minus dissolved metal. A part of what is measured as dissolved metal is particulate metal that is small enough to pass through the filter, or that is adsorbed to or complexed with organic colloids and ligands. Some or all of this may be biologically unavailable.

EPA defines the chemical *translator* (f_d) as the fraction (f) of the total recoverable metal in the surface water that is dissolved ($_d$). The *translator* can be used to estimate the concentration of dissolved metal from measured total metal values, or vice versa. The most reliable translators are produced from site-specific data. Two procedures can be used to develop site-specific translators. Complete guidance for determining a site-specific translator is provided by EPA (USEPA 1996). The most straightforward approach is to analyze directly the dissolved and total recoverable fractions. In this approach, a number of samples are taken over time and an f_d value is determined

$$f_d = \frac{C_d}{C_t} \qquad \text{(Equation 2)}$$

for each sample, where:

where:

C_d = the dissolved (operationally-defined) concentration of chemical in water

C_t = the total concentration of chemical in water

The translator is then calculated as the geometric mean (GM) of the dissolved fractions (f_ds) .

The second approach is to derive f_d from the use of a partition coefficient, K_d, where usually the coefficient is determined as a function of total suspended solids (TSS) (although some other basis such a humic substances or particulate organic carbon may be used).

4.2 Objective

To expand the BAF database for arsenic, a chemical translator was required to derive BAFs from water concentration data reported as total arsenic. Translators and/or related K_d values can be generated from an acceptable existing literature-derived data base. To gather this data base, peer-reviewed literature papers from 1985 to present were searched and reviewed. All data identified in the literature were required to meet the following criteria in order to be used it in developing the translator:

- Appropriate techniques were used in sampling and analysis.
- Adequate QA/QC procedures were used.
- Analytical methods used provided sufficiently low detection level.

Given the available data it was possible to determine the relative fractions of total and dissolved arsenic in ambient surface waters, and hence generate a translator for total arsenic, but it is not possible to determine the total and dissolved fractions of inorganic arsenic, AsB, AsC, and DMA.

4.3 Results and Discussion

The results of the literature review are presented in Table 4-1. Due to the paucity of data found, these f_d results are presented for combined lake, river and estuarine systems. The data represent four lotic, two lentic, one estuarine, and one lotic-lentic combined systems. Clearly, insufficient data were obtained to provide reliable f_d (translator) values for arsenic for individual systems. The translator for total dissolved arsenic derived from the recent literature data base (Table 4-1) is 0.84.

Little information that would allow for development of translator values for individual dissolved arsenic species was found. Only two articles (Anderson and Bruland, 1991; Michel et al., 2001) contained adequate data for use in calculating arsenic species translators. In addition, the dynamic inter-conversion that occurs between arsenic species all but precludes use of arsenic species translators. Thermodynamically predicted As(V)/As(III) ratios are rarely observed in natural surface waters, and experimental evidence clearly indicates that a multiplicity of factors influences the relative concentrations of these species (Cullen and Reimer 1989; Smedley and Kinniburg 2002). The interconversion of arsenite and arsenate by algal/bacteria transformations prevents achievement of thermodynamic equilibrium. A recent survey of surface drinking water sources in the U.S. found that about two thirds of the soluble arsenic was As(V) arsenate, and about one third was in the As(III) arsenite form (Chen et al. 1999). Concentrations and relative proportions of As(V) and As(III) vary according to changes in input sources, redox conditions, pH, and biological activity. The presence of As(III) may be maintained in oxygenated waters by biological reduction of As(V), particularly during summer months. Proportions of As(III) and As(V) are particularly variable in stratified lakes where redox gradients and biological activity can be large and seasonally variable.

For example, Anderson and Bruland (1991) found an f_d value of 0.34 for As(V) in Davis Reservoir, CA surface water in October, 1988, but an f_d value of 0.87 was measured in February, 1989. Similarly, an f_d value determined for dimethyarsenic acid (DMA) was 0.419 in October but was found to be <0.01 in February, showing the large seasonal variability of the arsenic species f_ds. Variability was encountered with depth of sample also (an f_d of 0.42 for DMA on the surface but an f_d of 0.01 at 17.7 m depth in the reservoir in October, 1988). Therefore, because of the dynamic transformations and variability of species, no attempt has been made to present species specific arsenic translators.

4.4 Application of the Chemical Translator for BAF Calculations

Application of the arsenic translator to the saltwater BAF data set was not required because all values for arsenic in water were already provided in the desired form (total dissolved arsenic). The translator was used for two lotic studies and one lentic study in the freshwater dataset. The BAF data to which the translator was applied was primarily for trophic level 3 and 4 freshwater organisms. Because the BAFs estimated for these organisms were generally very low, the use of the translator did not greatly alter the original BAF estimate. The use of the translator permitted the calculation of additional BAFs in 12 instances for freshwater fish species and 5 instances for freshwater invertebrate species.

TABLE 4-1: Dissolved Arsenic as a Fraction of Total Arsenic in Surface Waters

f_d Value	Location	Reference
0.62	Surface Drinking Water Sources, U.S.	Chen et al. 1999
0.74	Ogeechec River, GA	Waslenchuk 1979
0.81	Los Angeles Aquaduct Channel, CA	Hering and Kneebone 2002
0.87	Tanagawa and Saganigawa Rivers, Japan	Tanzaki et al. 1992
0.88	Upper Mystic Lake, MA	Chen and Folt 2000
0.92	Davis Creek Reservoir, CA	Anderson and Bruland1991
0.94	Seine River, France	Michel et al. 2001
0.94	Thames Estuary, England	Millward et al. 1997

GM= 0.84 Range 0.62 - 0.94

5.0 ARSENIC SPECIATION IN TISSUES OF AQUATIC ORGANISMS

As indicated in the Introduction to this document, there exists in the literature a general consensus that from 85% to >90% of arsenic found in edible portions of marine fish and shellfish is in an organic form [(arsenobetaine (AsB), arsenocholine (AsC), dimethyl arsinic acid (DMA)] and that approximately 10% is inorganic arsenic species [As(III), As(V)]. Less is known about the forms of arsenic in freshwater fish, but the available evidence suggests inorganic forms predominate over organic forms (AsB, AsC). Marine algae accumulate inorganic arsenic from seawater and incorporate it into an array of carbohydrate compounds known as arsenosugars. Arsenosugars are precursors in the metabolic pathway to AsB and AsC which may explain the source of these latter forms in marine animals (Hansen et al. 2003). Currently, there is no similar information on freshwater phytoplankton. This section includes a compilation of the available information regarding the relative fractions of inorganic and organic (e.g, AsB, AsC, DMA) arsenic in freshwater and marine aquatic organisms by trophic level. These data are useful for understanding the transformation of arsenic in tissues of organisms within the aquatic food web, and for considering and approximating possible BAFs based on the various forms of arsenic present in animal tissue.

5.1 Freshwater Aquatic Organisms

5.1.1 Trophic Level 2

Very little field data exists to determine the relative fractions of the various arsenic forms in tissues of trophic level 2 organisms in freshwater systems. For example, no data were found for trophic level 2 organisms in lentic ecosystems, and only a single study contains this type of information in lotic ecosystems. Kaise et al. (1997) reported the arsenic species present in arsenic-rich river water and the corresponding arsenic body burden in aquatic invertebrates from the Haya-kawa River in Hakone, Kanagawa, Japan. The river water at the site where the organisms were collected contained 3.0×10^{-2} mg/L total arsenic, 93% of which was inorganic and the remaining 7% trimethylated arsenic. The corresponding chemical speciation of arsenic in whole body tissue of trophic level 2 organisms varied greatly between species. Caddisfly larvae and pupae were composed mostly of dimethylarsenic (DMA) compounds, 86% and 56%, respectively, while the marsh snail contained only about 27% (Table 5-1). The remainder of the total arsenic burden in the whole body of these organisms was identified as trimethylarsenic compounds, which is commonly distinguished as AsB or AsC in marine fish. Very little inorganic arsenic was detected in these organisms. These findings are meaningful in that nearly all of the arsenic accumulated naturally by these particular freshwater organisms in the Haya-kawa River was biomethylated.

Substantially more data are available on the various forms of arsenic present in tropic level 2 organisms exposed to arsenic as either arsenate [As(V)] or arsenite [As(III)] in laboratory experiments. Modified Detmer medium was used as the laboratory dilution water in all of the laboratory studies. The experimental designs were such that water-only and dietary (2 or 3 step laboratory food-chain model) arsenic exposure was included.

Suhendrayatna et al. (2001,2002a, 2002b) investigated the bioaccumulation and biotransformation of arsenite [As(III)] by the waterflea, *Daphnia magna*, and red cherry shrimp, *Neocaridina denticulata*. Waterfleas exposed for 7 days to arsenite under static conditions at concentrations ranging from 0.05 to 1.5 mg/L contained from 63% to 75% As(III) and from 24% to 36% As(V), with geometric means of approximately 70 and 28%, respectively (Table 5-1). The relative fraction of DMA measured in their whole body tissues was less than 2%. Shrimp exposed under similar conditions to water containing from 0.1 to 1.5 mg/L arsenic as arsenite contained from 37% to 48% As(III) and from 22% to 56% As(V), with geometric means of approximately 43 and 35%, respectively (Table 5-1). The relative fraction of DMA in whole body was markedly higher for shrimp ranging from 7% to 32%. In contrast, for waterfleas fed a diet of arsenite-dosed alga (*Chlorella vulgaris*) which contained approximately 83% As(V), 9% As(III), and only 6% DMA, the fraction of As(III) and As(V) in their tissues was nearly 50:50, while in shrimp, a much greater percentage existed as As(V) (80 to 90%), the remainder in the form of As(III) (Table 5-1). In both cases, regardless of exposure type (water-only or dietary), inorganic arsenic was accumulated as the predominant arsenic species in these organisms, with relatively little indication of biomethylation. Similar observations were made for the red cherry shrimp exposed to arsenic as arsenate in the medium (Maeda et al. 1992, 1993), whereas the relative fraction of organic arsenic (measured as DMA) in the zooplankter *Moina macrocopa* exposed to arsenic as arsenite in the medium was much higher, approximately 55% (Maeda et al. 1990).

In general, for trophic level 2 organisms exposed to arsenic as either arsenite or arsenate in laboratory water, approximately 80% of their tissue body burden remains in the inorganic forms, while less than 10% to 20% is biomethylated. The same appears to be true when these organisms are exposed to arsenic via their diet. The observations differ substantially from those reported by Kaise et al. (1997) who examined trophic level 2 organisms in field studies.

TABLE 5-1: Arsenic Speciation in Freshwater Trophic Level 2 Aquatic Organisms

Species	Test type	Fraction of Total Arsenic[a]				Reference
		Inorganic	As(III)	As(V)	Organic	
marsh snail	Field	NM	-	-	0.89	Kaise et al. (1987)
caddisfly larva	Field	NM	-	-	0.95	Kaise et al. (1987)
caddisfly pupa	Field	NM	-	-	0.99	Kaise et al. (1987)
zooplank. grazer	Lab; As(III) (water)	0.45	NM	NM	0.55	Maeda et al. (1990)
waterflea	Lab; As(III) (water)	-	0.70	0.28	0.012	Suhendrayatna et al. (2001)

red cherry shrimp	Lab; As(III) (water)	-	0.43	0.35	0.16	Suhendrayatna et al. (2001)
red cherry shrimp	Lab; As(V) (water)	0.83	NM	NM	0.15	Maeda et al. (1992, 1993)
zooplank. grazer	Lab; As(III) (diet)	0.81	NM	NM	0.24	Maeda et al. (1990)
waterflea	Lab; As(III) (diet)	-	0.44	0.56	-	Suhendrayatna et al. (2001, 2002a)
red cherry shrimp	Lab; As(III) (diet)	-	0.13	0.86	0.016	Suhendrayatna et al. (2001, 2002b)
red cherry shrimp	Lab; As(V) (diet)	0.88	NM	NM	0.056	Maeda et al. (1993)

[a]Values represent geometric mean; calculations based on data compiled in Appendix X.

5.1.2 Trophic Levels 3 and 4

The field study by Kaise et al. (1997) provides data on the proportion of organic arsenic (di- and trimethyl arsenic species) in several forage fishes, a piscivorous fish, a freshwater prawn, and dobsonfly larvae. In addition to these data, the relative fractions of inorganic arsenic and AsB in the tissues of crayfish caught in an area affected by a toxic mine-tailing spill near Seville, southern Spain were analyzed and reported by Devesa et al. (2002). In the former study, the range in percent dimethylarsenic compounds identified in trophic levels 3 and 4 species from Haya-kawa River in Hakone, Kanagawa, Japan, was quite large with Japanese dace, prawn, and dobsonfly larva each containing 76, 75, and 96% dimethylarsenic compounds, respectively, whereas other species including goby, downstream fatminnow, and sweet fish contained less than 25% of these dimethylated arsenic compounds, but a much greater percentage of trimethylarsenic. The single trophic level 4 fish represented in the dataset from this study, the masu salmon, contained about 43% dimethylarsenic compound and 55% trimethylarsenic compounds. Thus, although there appears to be very large differences in the form of biomethylated arsenic species present in tissues of aquatic organisms within each of the respective trophic levels, very little inorganic arsenic in tissues is present (Table 5-2).

By contrast, in the recent study by Devesa et al. (2002), crayfish from the River Guadiamar and Puente de los Vaqueros and Aguas Minimas Canal, Seville, Spain contained from 21% to 92% inorganic arsenic based on whole body analysis. The mean (geometric) fraction of inorganic arsenic in crayfish whole body tissue was about 54% (Table 5-2). The fraction of AsB in this species ranged from a mere 2% to less than 16% (geometric mean = 4%). Crayfish from experimental ponds raised near the contaminated study area contained similar mean fractions of the arsenicals (Table 5-2), 29% and 4%, respectively.

The findings of the various laboratory exposures of higher trophic level organisms, i.e., carp, tilapia, Japanese medaka, and guppy, exposed to arsenite and arsenate via the water in the Suhendrayatna and Maeda studies indicated that inorganic arsenic comprised a large portion of the total arsenic present in these animals, except for tilapia (Table 5-2). One observation from the Suhendrayatna et al. (2002b) experiment, however, is the fact that tilapia fish exposed to dimethylarsinic acid in water (nominal concentrations ranging from 1 to 50 mg/L) carried a body burden of approximately 94% organic arsenic (one third DMA related compounds and two thirds TMA related compounds), which is approximately two to three times higher than in tilapia exposed to any other form of arsenic from the same study (Table 5-2). These data imply that the amount of dimethylated arsenic chemical species in ambient surface waters may result in a greater proportion of total arsenic in aquatic biota existing in the organic form. The importance of the amount of organic arsenic in ambient surface water is further supported by the observation that very little of this form of arsenic was found in the whole bodies of tilapia and Japanese medaka exposed to arsenic as arsenite through a simulated 3-step food chain model (Suhendrayatna et al. 2002b, Table 5-2). In this particular study, arsenic residues in tilapia and Japenese medaka exposed to arsenite in water were actually higher than when they accumulated it via the food chain. The same was not true for guppies exposed via a simulated food chain where the arsenic in water was originally provided as arsenate (Maeda et al. 1990).

Mean fractions of inorganic and organic arsenic in dorsal muscle of carp exposed to arsenic as arsenate in water do not differ substantially from the corresponding whole body concentrations measured for other fishes (Maeda et al. 1993).

TABLE 5-2: Arsenic Speciation in Freshwater Trophic Levels 3 and 4 Aquatic Organisms

Species	**Test type**	**Fraction of Total Arsenic[a]**				**Reference**
		Inorganic	**As(III)**	**As(V)**	**Organic**	
dobsonfly larvae	Field	NM	-	-	0.96	Kaise et al. (1997)
freshwater prawn	Field	NM	-	-	0.75	Kaise et al. (1997)
amphidromous goby	Field	NM	-	-	0.97	Kaise et al. (1997)
Japanese dace	Field	NM	-	-	0.96	Kaise et al. (1997)
downstream fatminnow	Field	NM	-	-	0.97	Kaise et al. (1997)
goby	Field	NM	-	-	0.95	Kaise et al. (1997)
sweet fish	Field	NM	-	-	0.88	Kaise et al. (1997)
masu salmon	Field	NM	-	-	0.99	Kaise et al. (1997)

crayfish	Field	0.54	NM	NM	0.04	Devesa et al. (2002)
crayfish	Field	0.29	NM	NM	0.04	Devesa et al. (2002)
tilapia	Lab; As(III) (water)	-	0.25	0.14	0.50	Suhendrayatna et al. (2001)
tilapia	Lab; As(V) (water)	-	0.36	0.36	0.25	Suhendrayatna et al. (2002b)
tilapia	Lab; As(III) (water)	-	0.37	0.24	0.37	Suhendrayatna et al. (2002b)
tilapia	Lab; MMA (water)	-	0.40	0.31	0.27	Suhendrayatna et al. (2002b)
tilapia	Lab; DMA (water)	-	-	-	0.94	Suhendrayatna et al. (2002b)
Japanese medaka	Lab; As(III) (water)	-	0.45	0.38	0.06	Suhendrayatna et al. (2002a)
guppy	Lab; As(V) (water)	0.78	NM	NM	0.21	Maeda et al. (1990)
carp	Lab; As(V) (water)	0.76	NM	NM	0.19	Maeda et al. (1993)
tilapia	Lab; As(III) (diet)	-	0.41	0.56	0.023	Suhendrayatna et al. (2001)
tilapia	Lab; As(III) (diet)	-	0.41	0.44	0.037	Suhendrayatna et al. (2002b)
Japanese medaka	Lab; As(III) (diet)	-	0.26	0.74	0.0	Suhendrayatna et al. (2002a)
guppy	Lab; As(V) (diet)	0.15	NM	NM	0.84	Maeda et al. (1990)

[a]Values represent geometric mean; calculations based on data compiled in Appendix X.

5.2 Saltwater Aquatic Organisms

Most of the available arsenic speciation data in tissues of saltwater organisms are from field studies. The majority of these data pertain to marine bivalve molluscs, and all of it from soft or edible tissues. Clearly, only a very small percentage of inorganic arsenic exists in the soft tissues of these organisms (most often less than 1%), the bulk of it being in the form of AsB. The studies by De Gieter et al. (2002), Goessler et al. (1997), and Ochsenkuhn-Petropulu et al. (1997), confirm the general assertion that from 85% to >90% of arsenic found in edible portions of marine fish and shellfish is organic arsenic (primarily AsB).

Geizinger et al. (2002) recently showed that the total arsenic concentration in marine polychaetes *Nereis diversicolor* and *N. virens* (Geizinger et al. 2002) was about 70% water-soluble and consisted of approximately 60% AsB and 20 to 30% tetramethylarsonium ion. Tetramethylarsoniopropionate and arsenosugars were also present as minor constituents. When the polychaetes were exposed in the laboratory to different concentrations of arsenate in seawater (0.010, 0.050, 0.100, 0.500, and 1.0 mg/L arsenic), the arsenic taken up by the polychaetes was readily methylated with the major metabolite as tetramethylarsonium ion (up to 85% of the accumulated arsenic). Methylation is assumed to be a process of detoxification, and the authors note the fact that tetramethylarsonium ion is a common compound in marine organisms, which suggests that this methylating ability is not restricted to *Nereis* sp.

6.0 SUMMARY OF ARSENIC BAFs AND SUPPORTING INFORMATION

6.1 Freshwater and Saltwater Arsenic BAFs

The present data compilation indicates that insufficient data are available to determine if distinguishing separate BAFs for freshwater lotic and lentic ecosystems is warranted, and the only data available for estimating field-derived arsenic BAFs for estuarine and marine ecosystems is for trophic level 2 organisms.

The species-mean BAFs for saltwater organisms are on average several times higher than for the majority of trophic level 2 organisms in the two freshwater ecosystem types. This apparent difference in arsenic BAFs calculated for freshwater and saltwater trophic level 2 organisms indicates the possible need to derive separate BAF values for arsenic in the two water types.

6.2 BAFs Based on Total Arsenic versus Other Forms of Arsenic

The hypothesis that BAFs based on total arsenic may not be representative of all freshwater ecosystems, and especially saltwater ecosystems, due to variation in the various forms of arsenic present in the water and tissues of organisms from those systems remains an issue requiring further consideration. Average concentrations of arsenic in ambient freshwater are generally <1 to 10 µg/L, and arsenic in seawater is present at a fairly uniform concentration of 2 µg/L (Smedley and Kinniburgh 2002). Concentrations of As in lake waters are typically close to or lower than those found in river waters. Some polluted rivers and lakes show levels of arsenic in the hundreds of ppb.

The environmental behavior of arsenic is dependent on the physical and chemical properties, toxicity, mobility, and biotransformation of *individual arsenic compounds*. Arsenic can occur in the environment in several oxidation states (0, +3 and +5), but in natural waters is mostly found in inorganic form as oxyanions of trivalent arsenite [As(III)] or pentavalent arsenate [As(V)]. Naturally occurring organo-arsenic compounds are described as having either As(III) or As(V) oxidation numbers. For example, the designated oxidation states in $(CH_3)_3As$ is As(+III) and in $(CH_3)_3AsO$ is As(+V) (Cullen and Reimer 1989). In oxygenated waters, inorganic arsenic acid (As(V)) species–H_3AsO_4, $H_2AsO_4^{-}$, $HAsO_4^{2-}$, and AsO_4^{3-}–are stable. Under slightly reducing conditions and/or lower pH arsenous (As(III)) acid becomes stable, mainly as neutral H_3AsO_3 (Cullen and Reimer 1989).

The range of arsenic species is more restricted when the pH domain of natural water is considered. Freshwater systems rarely exceed a pH range of 5-9 and the maximum pH distribution in seawater is 7.5-8.3. Thus As(V) should dominate over As(III) in oxygenated waters–at least on thermodynamic grounds. For examples, As(V)/As(III) ratios of 10^{15}-10^{26} have been calculated for seawater. Furthermore, As(V) should mainly consist of $HAsO_4^{2-}$ in oxygenated seawater (calculations show 98% $HAsO_4^{2-}$ and 1% each of $H_2AsO_4^{-}$ and AsO_4^{3-}). In fresh water of pH 6, $H_2AsO_4^{-}$ becomes dominant (89% versus 11% $HAsO_4^{2-}$). Inorganic As(III) species should mainly be neutral, as H_3AsO_3. The solution properties of arsenic acid

(H_3AsO_4) closely resemble those of phosphoric acid (H_3PO_4) and the ionization behavior of $As(OH)_3$ more closely resembles that of boric acid. Thermodynamically predicted As(V)/As(III) ratios are rarely observed, and experimental evidence clearly indicates that a multiplicity of factors influences the relative concentrations of these species. Paramount among these are biologically mediated redox reactions. The interconversion of arsenite and arsenate by algal/bacteria transformations prevents achievement of thermodynamic equilibrium. Concentrations and relative proportions of As(V) and As(III) vary according to changes in input sources, redox conditions and biological activity. The presence of As(III) may be maintained in oxic waters by biological reduction of As(V), particularly during summer months. Proportions of As(III) and As(V) are particularly variable in stratified lakes where redox gradients and biological activity can be large and seasonally variable.

Organoarsenic compounds are widely distributed in the environment. The origin of essentially all organoarsenicals starts with biomethylation of inorganic arsenic species. The principal biomethylation products are:

- Monomethylarsonate (MMA) CH_3AsO_2OH '
- Dimethylarsenate (DMA) $(CH_3)_2AsOO$ '
- Trimethylarsine (TMA) $(CH_3)_3As$
- Trimethylarsine oxide (TMAO) $(CH_3)_3AsO$
- Arsenobetaine (AsB) $(CH_3)_3As$%CH_2COOH
- Arsenocholine (AsC) $(CH_3)_3As$%$(CH_2)_2OH$

also, arsenoribosides and arsenophospholipids are formed. MMA and DMA are the organoarsenics usually encountered in surface waters and usually do not exceed 10% of the total dissolved arsenic. However, some seasonally anoxic lakes have shown methylated forms to be the dominate temporal species(>50%) of dissolved arsenic within the surface photic zone as a result of phytoplankton activity. Clearly, the speciation of arsenic in natural surface waters depends upon pH, DO (dissolved oxygen) and corresponding oxidation potential (Eh), and biological activity.

The only field data identified in our literature search for which concentrations of corresponding inorganic and organic arsenic in both the water and tissues of aquatic organisms are from Kaise et al. (1997). In their study of the arsenic species present in arsenic-rich river water from the Haya-kawa River at hot springs in Hakone, Kanagawa, Japan, the authors showed that the river water at the site where the organisms were collected contained 3.0×10^{-2} mg/L total arsenic, 93% of which was inorganic and the remaining 7% trimethylated arsenic. The corresponding chemical speciation of arsenic in whole body tissue of the various organisms collected there varied greatly between species, but were composed mostly of dimethylarsenic (DMA) and trimethylarsenic (TMA) compounds, which are commonly distinguished as AsB or AsC in marine fish. The corresponding BAFs based on the organic fraction of arsenic in water and tissues of these organisms ranged from 26 to 1,590 L/kg, compared to 2.0 to 114.1 L/kg based on total arsenic; an increase of a factor of ten. In contrast, in the laboratory studies composed by Spehar et al. (1980), there was no difference in BCFs for several freshwater invertebrate species exposed to inorganic arsenic either as As(III) or As(V), or organic arsenic as DMA or MMA (see Table 3-1). Much more field data are required to adequately compare and support the derivation of separate BAFs for the various forms of arsenic in ambient surface waters.

6.3 Arsenic in Tissues of Freshwater and Saltwater Aquatic Organisms

The tissue data collected from this literature search for bioaccumulation of arsenic appear to confirm earlier assumptions that the majority of arsenic in saltwater organisms is arsenobetaine (AsB), with only a relatively small fraction of the total arsenic in these organisms existing in the inorganic form. However, these observations are based on data for relatively few saltwater species.

A finding for freshwater organisms is that a very high percentage of organic arsenic in the tissues of animals collected from the arsenic-rich (containing approximately 93% inorganic arsenic) Haya-kawa River, Japan (Kaise et al. 1997). These observations run counter to those observed for like animals exposed to arsenic (delivered as inorganic arsenic) in laboratory water-only and food-chain experiments (Suhendrayatna et al. 2001, 2002a,b; Meada et al. 1990, 1992, 1993). The reason for this apparent discrepancy in results cannot be easily explained. It would appear that rates of biomethylation for aquatic organisms in the field may greatly exceed those for like organisms exposed to arsenic in a laboratory setting.

In general, the concentrations of total arsenic in marine and estuarine bivalve molluscs (data from the National Oceanic and Atmospheric Administration's Mussel Watch Program, National Status and Trends) and saltwater fish (data for flounder from EPA's Mid-Atlantic Integrated Assessment Program) greatly exceed those in freshwater fishes (Lowe et al. 1985; Schmitt and Brumbaugh 1990). Typical background total arsenic levels in the respective organisms (marine bivalves, flounder, freshwater fish) are in the range of 1 to 2 mg/kg, 0.75 to 2.5 mg/kg, and 0.10 to 0.25 mg/kg wet weight, respectively. Clearly, more field studies are needed regarding the biogeochemical cycling of arsenic in aquatic environments and the biological fate and disposition of arsenic in both freshwater and saltwater organisms.

7.0 CONCLUSIONS

This document presents the information and methodologies used to support EPA's current effort to update the existing 304(a) human health ambient water quality criteria (AWQC) for arsenic. The BAF values calculated from raw data of appropriate studies are summarized in Appendices B through D and appear in various tables throughout the text. Only those total dissolved arsenic BAFs estimated directly from field-measured data were included in the summary tables and used to calculate species-mean BAFs. Insufficient data were available to support the derivation of BAFs for other forms of arsenic (i.e., organic, inorganic; see Section 6.2). BAFs estimated from laboratory BCF experiments are presented, but are not considered robust for estimating BAFs because the majority of the values generated from these studies did not meet data acceptability criteria and because the estimated BCFs were lower than BAFs calculated using field-data.

Data on the uptake and accumulation of arsenic in estuarine and marine shellfish representative of those regularly consumed by humans were very limited. Species-mean BAFs were calculated for four saltwater species, all of which were trophic level 2 organisms.

Chemical speciation data for arsenic in fresh and salt surface water was limited. Insufficient data were obtained to provide reliable f_d (translator: dissolved/total) values for arsenic for the individual systems specified in this document. An interim default chemical translator value of 0.84 (range 0.62 to 0.94) based on four lotic, two lentic, one estuarine, and one lotic-lentic combined systems was generated for arsenic in this document.

Information available that may be useful for determining bioaccumulation factors for arsenic is compiled in this document. National trophic-level specific BAFs are not included in this document because OST is in the process of determining if the data identified in our literature search is sufficient to derive national BAFs. In the interim, we are making the results of the literature search available to States and authorized Tribes so that they have access to a current compilation and review of available data as they develop State and Tribal Water Quality Standards.

8.0 REFERENCES

Anderson, L.C.D., and K.W. Bruland. 1991. Biogeochemistry of arsenic in natural waters: he importance of methylated species. Environ. Sci. Technol. 25:420-427.

Baker, D.L. and K.A. King. 1994. Environmental contaminant investigation of water quality, sediment and biota of the Upper Gila River Basin, Arizona. Project No. 22410-1130-90-2-053. U.S. Fish and Wildlife Service, Phoenix, AZ.

Barrows, M.E., S.R. Petrocelli, K.J. Macek, J.J. Carroll. 1980. Bioconcentration and elimination of selected water pollutants by bluegill sunfish (*Lepomis macrochirus*). In: Dynamics, Exposure and Hazard Assessment of Toxic Chemicals. R. Haque (ed.). Ann Arbor Science Pub., Inc., Ann Arbor, MI. pp. 379-392.

Bart, H.L., Jr., P.J. Martinat, A. Abdelghani, P.B. Tchounwou and S.L. Taylor. 1998. Influence of taxonomy, ecology, and seasonality in river stage on fish contamination risks in flood plain swamps of the lower Mississippi River. Ecotoxicology. 7:325-334.

Cain, D.J., S.N. Luoma, J.L. Carter, and S.V. Fend. 1992. Aquatic insects as bioindicators of trace element contamination in cobble-bottom rivers and streams. Can. J. Fish. Aquat. Sci. 49: 2141-2154.

Chen, C.Y., and C.L. Folt. 2000. Bioaccumulation and diminution of arsenic and lead in a freshwater food web. Environ. Sci. Technol. 34:3878-3884.

Chen, C.Y., R.S. Stemberger, B. Klaue, J.D. Blum, P.C. Pickhardt, and C.L. Folt. 2000. Accumulation of heavy metals in food web components across a gradient of lakes. Limnol. Oceanogr. 45:1525-1536.

Chen, H., M.M. Frey, D. Clifford, L.S. McNeil, and M. Edwards. 1999. Arsenic treatment considerations. J. AWWA, 91:74-85.

Cooper, C.M., and W.B. Gillespie Jr. 2001. Arsenic and mercury concentrations in major landscape components of an intensively cultivated watershed. Environ. Pollut. 111:67-74.

Cullen, W.R., and K.J. Reimer. 1989. Arsenic speciation in the environment. Chem. Rev. 89:713-764.

De Gieter, M., M. Leemakers, R. Van Ryssen, J. Noyen, L. Goeyens, and W. Baeyens. 2002. Total and Toxic Arsenic Levels in North Sea Fish. Arch. Environ. Contam. Toxicol. 43:406-417.

Devesa, V., M.A. Suner, V.W.-M. Lai, S.C.R. Granchinho, J.M. Martinez, D. Velez, W.R. Cullen, and R. Montoro. 2002. Determination of arsenic species in a freshwater crustacean *Procambarus clarkii*. Applied Organometal. Chem. 16:123-132.

Francesconi, K.A., J. Gailer, J.S. Edmonds, W. Goessler, K.J. Irgolic. 1999. Uptake of arsenic-betaines by the mussel *Mytilus edulis*. Comp. Biochem. Physiol. C. 122:131-137.

Gailer, J., K.A. Francesconi, J.S. Edmonds, and K.J. Irgolic. 1995. Metabolism of arsenic compounds by the blue mussel *Mytilus edulis* after accumulation from seawater spiked with arsenic compounds. Appl. Organometal. Chem. 9:341-355.

Geiszinger, A.E., W.Goessler, and K.A. Francesconi. 2002. Biotransformation of arsenate to the tetramethylarsonium ion in the marine polychaetes *Nereis diversicolor* and *Nereis virens*. Environ. Sci. Technol. 36(13):2905-2910.

Giusti, L., and Hao Zhang. 2002. Heavy metals and arsenic in sediments, mussels and marine water from Murano (Venice, Italy). Environ. Geochem. Health. 24: 47-65.

Goessler, W., W. Maher, K.J. Irgolic, D. Kuehnelt, C. Schlagenhaufen, and T. Kaise. 1997. Arsenic compounds in a marine food chain. Fresenius J. Analyst Chem. 359:434-437.

Hansen, H.R., A. Raab, K.A. Francesconi, and J. Feldmann. 2003. Metabolism of arsenic by sheep chronically exposed to arsenosugars as a normal part of their diet. 1. Quantitative intake, uptake, and excretion. Environ. Sci. Technol. 37:845-851.

Hare, L., A. Tessier, and P.G.C. Campbell. 1991. Trace element distributions in aquatic insects: variations among genera, elements and lakes. Can. J. Fish. Aquat. 48: 1481-1491.

Hering, J.G. and P.E. Kneebone. 2002. Biogeochemical controls on arsenic occurrence and mobility in water supplies. In: W.T. Frankeberger (ed.). Environmental Chemistry of Arsenic, Marcel Dekker, NY. pp. 155-181.

Hung, T.-C., P.-J. Meng, B.-C. Han, A. Chuang, C.-C. Huang. 2001. Trace metals in different species of mollusca, water and sediments from Taiwan coastal area. Chemosphere 44: 833-841.

Hunter, D.A., W. Goessler, and K.A. Francesconi. 1998. Uptake of arsenate, trimethylarsine oxide, and arsenobetaine by the shrimp Crangon crangon. Mar. Biol. 131:543-552.

Johnson, A. and M. Roose. 2002. Inorganic arsenic levels in puget sound fish and shellfish from 303 (d) listed waterbodies and other areas. Washington State Department of Ecology. Environmental Assessment Program Olympia Washington. Publication no. 02-03-057.

Kaise, T., M. Ogura, T. Nozaki, K. Saithoh, T. Sakurai, C. Matsubara, C. Watanabe, and K. Hanaoka. 1997. Biomethylation of arsenic in an arsenic-rich freshwater environment. Appl. Organom. Chem. 11:297-304.

Kitchin, K.T. and S. Ahmad. 2003. Oxidative stress as a possible mode of action for arsenic carcinogenesis. Toxicology Letters. 137:3-13.

Langston, W.J. 1984. Availability of arsenic to estuarine and marine organisms: a field and laboratory evaluation. Marine biology. 80:143-154.

Lin, M.-C., C.-M. Liao, C.-W. Liu, S. Singh. 2001. Bioaccumulation of arsenic in aquacultural large-scale mullet *Liza macrolepis* from Blackfoot Disease area in Taiwan. Bull. Environ. Contam. Toxicol. 67: 91-97.

Lowe, T.P., T.W. May, W.G. Brumbaugh, and D.A. Kane. 1985. National contaminant biomonitoring program: Concentrations of seven elements in freshwater fish, 1978-1981. Arch. Environ. Contam. Toxicol. 14:363-388.

Maeda, S., K. Mawatari, A. Ohki, and K. Naka. 1993. Arsenic metabolism in a freshwater food chain: Blue-green alga (*Nostoc* sp.)6 shrimp (*Neocardina denticulata*)6 carp (*Cyprinus carpio*). Appl. Organom. Chem. 7:467-476.

Maeda, S., A. Ohki, K. Kusadome, T. Kuroiwa, I. Yoshifuku, and K. Naka. 1992. Bioaccumulation of arsenic and its fate in a freshwater food chain. Appl. Organom. Chem. 6:213-219.

Maeda, S., A. Ohki, T. Tokuda and M. Ohmine. 1990. Transformation of arsenic compounds in a freshwater food chain. Appl. Organom. Chem. 4:251-254.

Mason, R.P., J.-M. Laporte, and S. Andres. 2000. Factors controlling the bioaccumulation of mercury, methylmercury, arsenic, selenium, and cadmium by freshwater invertebrates and fish. Arch. Environ. Contam. Toxicol. 38:283-297.

McIntyre, D.O., C.G. Delos, W.H. Clement and T.K. Linton. 2002. BAFs for selenium: Implications for implementation of a tissue-based chronic criterion. Abstract Book. SETAC 23rd Annual Meeting in North America, Salt Lake City, UT 16-20 November, 2002. Society of Toxicology and Chemistry. Abstract No. 042. p. 13.

MDEQ (Michigan Department of Environmental Quality). 1996. Michigan default metals translator. MI/DEQ/SWQ-95/085. Lansing, MI.

Michel, P., B. Averty, J.-F. Chiffoleau, and L.-A. Romana. 2001. Biogeochemical behavior of arsenic species in the seine estuary in relation of successive high-amplitude primary production, anoxia, turbidity, and salinity events. Estuaries. 24:1066-1073.

Millward, G.E., H.J. Kitts, L. Ebdon, J.I. Allen and A.W. Morris. 1997. Arsenic in the Thames Plume, UK. Marine Environmental Research. 44:51-67.

Ochsenkühn-Petropulu, J. Varsamis, and G. Parissakis. 1997. Speciation of arsenobetaine in marine organisms using a selective leaching/digestion procedure and hydride generation atomic absorption spectrometry. Analytica Chimica Acta. 337:323-327.

Schmitt, C.J. and W.G. Brumbaugh. 1990. National contaminant biomonitoring program: Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19:731-747.

Skinner, W.F. 1985. Trace element concentrations in wastewater treatment basin-reared fishes: Results of a pilot study. Proceedings of the Pennsylvania Academy of Science. 59:155-161.

Smedley, P.L., and D.G. Kinniburgh. 2002. A review of the source, behaviour and distribution of arsenic in natural waters. Applied Geochemistry 17:517-568.

Spehar, R.L., J.T. Fiandt, R.L. Anderson, and D.L. DeFoe. 1980. Comparative toxicity of arsenic compounds and their accumulation in invertebrates and fish. Arch. Environm. Contam. Toxicol. 9:53-63.

Suhendrayatna, A.O., T. Nakajima, and S. Maeda. 2002a. Studies on the accumulation and transformation fo arsenic in freshwater organisms I. Accumulation, transformation and toxicity of arsenic compounds to the *Japenese medaka, Oryzias latipes*. Chemosphere. 46:319-324.

Suhendrayatna, A.O., T. Nakajima, and S. Maeda. 2002b. Studies on the accumulation and transformation fo arsenic in freshwater organisms II. Accumulation and transforamtion of arsenic compounds by *Tilapia mossambica*. Chemosphere. 46:325-331.

Suhendrayatna, A.O., and S. Maeda. 2001. Biotransformation of arsenite in freshwater food-chain models. Applied Organometallic Chemistry. 15:277-284.

Tanizaki, Y., T. Shimokawa, and M. Nakamura. 1992. Physicochemical speciation of trace elements in river waters by size fractionation. Environ. Sci. Technol. 26:1433-1443.

Thomas, D.J., M. Styblo, and S. Lin. 2001. The cellular metabolism and systemic toxicity of arsenic. Toxicol. Appl. Pharm. 176: 127-144.

USEPA (United States Environmental Protection Agency). 2000. Methodology for deriving ambient water quality criteria for the protection of human health (2000). Office of Water, Washington, DC. EPA-822-B-00-004.

USEPA (United States Environmental Protection Agency). 1996. The metals translator: Guidance for calculating a total recoverable permit limit from a dissolved criteria, Washington, DC.

USEPA (United States Environmental Protection Agency). 1995. *Trophic level and exposure analyses for selected piscivorous birds and mammals. Volume II: Analyses of species in the conterminous United States. Draft*. Office of Water, Washington, DC.

USEPA (United States Environmental Protection Agency). 1993. Memo from Martha G. Prothro, Acting Assistant Administrator for Water, to Water Management Division Directors and

Environmental Services Division Directors, titled "Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria, Office of Water, Washington, DC.

USEPA (United States Environmental Protection Agency). 1985. Ambient aquatic life water quality criteria for arsenic - 1984. PB85-227445. National Technical Information Service, Springfield, VA.

Valette-Silver, N.J., G.F. Riedel, E.A. Crecelius, H. Windom, R.G. Smith, and S.S. Dolvin. 1999. Elevated arsenic concentrations in bivalves from the southeast coasts of the USA. Marine Environ. Research. 48:311-333.

Wagemann, R., N.B. Snow, D.M. Rosenberg, and A. Lutz. 1978. Arsenic in sediments, water and aquatic biota from lakes in the vicinity of Yellowknife, Northwest territories, Canada. Arch. Environm. Contam. Toxicol. 7:169-191.

Waslenchuk, D.G. 1979. The geochemical controls on arsenic concentrations in Southeastern United States River. Chemical Geology. 24:315-325.

Woolson, E.A. 1975. Bioaccumulation of arsenicals. In: Arsenical pesticides. E.A. Woolson (ed.). ACS Symposium Series 7. American Chemical Society, Washington, D.C.

Zaroogian, G.E., and G.L Hoffman. 1982. Arsenic Uptake and Loss in the American Oyster, Crassostrea Virginica. Environmental Monitoring and Assessment. 1:345-358.

APPENDIX A

BAF LITERATURE SEARCH STRATEGY

Literature Search Strategy
for
Data on Arsenic Bioaccumulation in Aquatic Organisms

The literature search strategy is designed to obtain all relevant information for the calculation (if data are available of bioaccumulation factors (BAFs) for total arsenic, total inorganic arsenic, dissolved inorganic arsenic, arsenobetaine (AsB), arsenocholine (AsC) and dimethyl aresinic acid (DMA).

A 'bioaccumulation' search was conducted with the objective of retrieving relevant information for arsenic in lotic, lentic and estuarine ecosystems. A 'translator' search was conducted to obtain additional information relevant to establishing chemical translators for arsenic. This search used a set of search terms different than those used in the primary search, and therefore eliminated the hits obtained in the primary search. Elements of the searches:

- Major Database: Chemical Abstracts
- Time Period for the Literature Search: 1980 through 2002

Bioaccumulation Search

Objective: To obtain information relevant for determining BAFs from acceptable field bioaccumulation or laboratory bioconcentration studies. The search used the following sets of search terms to obtain information relevant to deriving bioaccumulation factors for lotic, lentic, and marine/estuarine ecosystems:

- arsenic, arsenite, arsenate, arsine, arsenobetaine, arsenocholine, dimethyl arsinic acid (search included chemical name and/or CAS number)
- all the organisms listed in Attachment A-1
- bioaccumulat, or bioconcentrat, or accumulat, or biomagnif, or uptake, or depurat, or eliminat, or BAF, or BCF, or AF, or residue, or tissue, or food chain, or food web, or predator/prey, or PPF, or pharmacokinetic, or toxicokinetic

The titles and abstracts of those references that contained the three sets of search terms shown above (e.g., arsenic and walleye and bioaccumulat) were printed and reviewed by senior scientists/specialists. The titles and abstracts were reviewed for indication that the references contained the following information necessary for deriving bioaccumulation factors:

- the concentration of arsenic (or forms of interest) in the tissue of an aquatic organism (fish and invertebrates; mammal data were excluded)
- the concentration of the arsenic (or forms of interest) in water, and
- any indication that a predator-prey factor could be determined.

Articles containing the above information were retrieved, reviewed and data extracted and recorded in tables/spreadsheets for use in deriving BAFs.

Translator Search

Objective: To obtain information relevant for development of arsenic translators for lotic, lentic , and marine/estuarine ecosystems. The search used the following sets of search terms to obtain relevant:

- arsenic, arsenite, arsenate, arsine, arsenobetaine, arsenocholine, dimethyl arsinic acid (search included chemical name and/or CAS number)
- lotic, or river, or stream, or creek, or brook, or spring, or trib, or canal, or lentic, or lake, or pond, or water, or loch, or saltwater, or ocean, or marine, or sea, or delta, or harb, or waterway, or estuar, or bay, or inlet, or sound, or firth, or fjord, or mouth, or coast
- distribu, or speciation, or partition, or Kd, or dissolv, or fraction, or translat, or filter

The titles and abstracts of those references that contained the three sets of search terms shown above (e.g., arsenic and walleye and bioaccumulat) were printed and reviewed by senior scientists/specialists. Articles containing information on (1) the total and dissolved concentration of arsenic or forms of interest, or (2) the concentration of particulate arsenic and total suspended solids, or (3) arsenic partition coefficients were were retrieved, reviewed and data extracted and recorded in tables/spreadsheets for use in deriving BAFs.

ATTACHMENT A-1

abalone
acartia
aeolosoma*
agnatha
alevin
alewife
alga
ambystoma*
amoeb*
amphipod *
anchov*
annelid*
aquaculture
archannelid *
artemi*
aufwuchs
backswimmer
barnacle
bass
benth*
beetle
bivalv*
blackfl*
blenny
bluegill
boatman
bream
bryophyt*
bryozoa*
bullhead
caddisfl *
carassius
carp
catfish
centrarch *
ceriodaphni *
chaetognatha
chaetonotid*
char
charphyt*
chinook
chironom *
chlamydomonas
chlorophyt*
chrysophyt*
chub
ciliat*
cisco
cladocera*
clup*
cnidaria
coho
coleoptera*
conchostracan
copepod*
corbicula
coregon*
crab
cranefl*
crangon
crappie
crayfish*
crassostrea
croaker
crustacea*
cryptophyt*
ctenophor*
cyanophyt*
cyprini *
cyprinodon*
dab
dace
damself1*
daphni *
darter
diptera*
dobsonfl*
dolphin
dragonfl*
drum
duckweed
ecihno*
eel
ephemer*
esoc*
esox
etheostoma
euglen*
fingerling
fish
fishes
flounder
fundulus
gambusia
gammar*
gar
gastropod *
gastrotrich*
goby
goldfish
grunIon
guppy
guppIes
haddock
hemiptera
herring
hexagenia
hirudin *
hyallela
hydra
hydridae
hydroid
hydrozoa
hyla
ictalur*
isopod*
jordanella
kelp
killifish
lamprey
lancelet
leech
lemna
lepomis
lobster
lymnaea
macoma
mayfl*
medaka

menhaden
menidia
mIcropogon
micropterus
midge
minnow
mollus*
molly
morone
mosquito *
mudminnow
mullet
mummichog
muskellunge
mussel
mysid*
mytilus
naupli*
neanthes
nereis
notropis
odonata
oligochaet*
oncorhynchus
osmerid*
osteichthyes
ostracod
ostre*
oyster
palaemon*
paramec*
parr
pelecypod*
penae*
perch
perci*
periphyt*
phaeophyt*
philodin*
physa
phytoplankton *
pike
pimephaeles
pinfish
pipefish
plaice
planari*
plankton*
platyfish
plecoptera
polychaet*
pompano
porifera
porpoIse
prawn
protozo*
puffer
pyrrophyt*
quahog
rhinichthy*
rhodophyt*
roach
roccus
rockfish
rotifer*
salmo*
salvelinus
sanddab
sauger
scallop
sciaenid*
scud
sculpin
seagrass
seaweed
selnastrum
shad
shellfish
sheep shead
shiner
shrimp
silverside
skeletonema
smelt
smolt
snail
sockeye
sole
spong*
spot
squid
squawfish
starfish
steelhead
stickleback
stonefl*
sturgeon
sucker
sunfish
surfclam
tench
tilapia
toad*
trematod *
trichoptera
trout
tubificid*
tubifex
tuna
turbellar*
urchin
walleye
whitefish
wonn
wrasse
zooplankton*

APPENDIX B

SUMMARY OF ARSENIC BIOACCUMULATION STUDIES REVIEWED

APPENDIX B: Summary of Arsenic Bioaccumulation Studies Reviewed														
Article #	Field or Lab	Water or Waterbody Type	Habitat Type	Species	Common Name	Trophic Level	Chemical Form Water	Chemical Form Tissue	Reject or Accept	BAF/BCF provided in paper? Y=Yes N=No	Reason for Rejection	Water Speciation Data?	Tissue Speciation Data?	Notes
1	Lab	Modified Detmer medium	NA	Chlorella vulgaris	green algae	1	Arsenite	Total, Inorganic, Organic	Reject	N	No indication that steady-state was achieved. Water concentrations not measured.	N	Y	7-day exposure (static). Includes speciation in tissue from wateborne and dietary exposure (lab food chain study). Dietary exposure of greater significance in lower trophic levels. No indication of bioamagnification.
1	Lab	Modified Detmer medium	NA	Daphnia magna	waterflea	2	Arsenite	Total, Inorganic, Organic						
1	Lab	Modified Detmer medium	NA	Neocardina denticulata	shrimp	2	Arsenite	Total, Inorganic, Organic						
1	Lab	Modified Detmer medium	NA	Tilapia mossambica	fish	3	Arsenite	Total, Inorganic, Organic						
1	Lab	Modified Detmer medium	NA	Zacco platypus	fish	3	Arsenite	Total, Inorganic						
2	Field	Rock pool at Rosedale NSW	Marine	Hormosira banksii	seaweed	1	NM	Inorganic, Organic	Reject	N	Water concentrations not measured.	N	Y	Tissue speciation useful for indicating differences in As species in the Marine food chain, but the arsenic species in tissues are not quantified.
2	Field	Rock pool at Rosedale NSW	Marine	Austrocochlea	gastropod	2	NM	Inorganic, Organic						
2	Field	Rock pool at Rosedale NSW	Marine	Morula marginalba	gastropod	4	NM	Inorganic, Organic						
3	Lab	Modified Detmer medium	NA	Chlorella vulgaris	green algae	1	Arsenite	Total, Inorganic, Organic	Reject	N	No indication that steady-state was achieved. Water concentrations not measured.	N	Y	7-day exposure (static). Does include speciation in tissue from wateborne and dietary exposure (lab food chain study). No indication of biomagnification in lab food chain.
3	Lab	Modified Detmer medium	NA	Daphnia magna	waterflea	2	Arsenite	Total, Inorganic						
3	Lab	Modified Detmer medium	NA	Oryzias latipes	Japanese medaka	3	Arsenite	Total, Inorganic						
4	Lab	Modified Detmer medium	NA	Tilapia mossambica	fish	3	Arsenite	Total, Inorganic, Organic	Reject	N	No indication that steady-state was achieved. Water concentrations not measured.	Y	Y	7-day exposure (static).
4	Lab	Modified Detmer medium	NA	Tilapia mossambica	fish	3	MMA	Total, Inorganic, Organic						
4	Lab	Modified Detmer medium	NA	Tilapia mossambica	fish	3	DMA	Total, Inorganic, Organic						
5	Field	Red River of the North, North Dakota	Lentic	Cyprinus carpio	common carp	3	NM	Total	Reject	N	Water concentrations were not measured.	N	N	Specimens collected at 4 sites. Study includes Total Arsenic in whole body, muscle, and liver tissue.
6	Lab	Lab Water	NA	Lepomis macrochirus	bluegill sunfish	3	Arsenite	Total	Reject	Y	Article states that steady-state conditions in bluegills did not appear to be reached during this period.	N	N	BCF of 4 reported for 28-day exposure period.
7	Field	Coal fly ash basin at US DOE	Lentic	Micropterus salmoides	largemouth bass	4	NM	Total	Reject	N	Water concentrations were not measured.	N	N	Study includes Total Arsenic in gill, gonad, liver, and muscle tissue. [As] is highest in liver tissue. Further analysis of gill and liver extracts from bass indicated that AB was not present.
7	Field	Fire Pond (unaffected by fly ash effluent)	Lentic	Micropterus salmoides	largemouth bass	4	NM	Total						
8	Field	Elevsis bay near Athens Greece	Marine	Mytilus edulis	blue mussel	2	NM	Total, AsB	Reject	N	Water concentrations were not measured.	N	Y	
8	Field	Elevsis bay near Athens Greece	Marine	Murex trunculus	marine snail	2	NM	Total, AsB						
9	Field	12 Coastal sites in western Taiwan	Marine		30 different marine molluscs	2	NM	Total	Uncertain	N	Concentrations of arsenic in water and sediment were measured, but not	N	N	
10	Field	6 Sites along the Lower Gila	Lotic	Cyprinus carpio	common carp	3	NM	Total	Reject	N	Water concentrations were not measured.	N	N	
10	Field	6 Sites along the Lower Gila	Lotic	Micropterus salmoides	largemouth bass	4	NM	Total						
10	Field	6 Sites along the Lower Gila	Lotic	Ictalurus punctatus	channel catfish	3	NM	Total						

APPENDIX B: Summary of Arsenic Bioaccumulation Studies Reviewed															
Article #	Field or Lab	Water or Waterbody Type	Habitat Type	Species	Common Name	Trophic Level	Chemical Form Water	Chemical Form Tissue	Reject or Accept	BAF/BCF provided in paper? Y=Yes N=No	Reason for Rejection	Water Speciation Data?	Tissue Speciation Data?	Notes
11	Field	7 Sites along the Santa Cruz	Lotic	Aeshnidae	dragonfly larvae	3	NM	Total	Reject	N	Water concentrations were not measured.	N	N	Sediment As concentrations reported.
11	Field	7 Sites along the Santa Cruz	Lotic	Belostoma sp.	giant water bug	3	NM	Total						
11	Field	7 Sites along the Santa Cruz	Lotic	Physa virgata	snail	2	NM	Total						
11	Field	7 Sites along the Santa Cruz	Lotic	Pantosteous clarki	desert sucker	3	NM	Total						
12	Field	11 Sites along the Middle Gila	Lotic	Cyprinus carpio	common carp	3	NM	Total	Reject	N	Water concentrations were not measured.	N	N	Sediment As concentrations reported.
12	Field	11 Sites along the Middle Gila	Lotic	Ictalurus punctatus	channel catfish	3	NM	Total						
12	Field	11 Sites along the Middle Gila	Lotic	Pantosteous clarki	desert sucker	3	NM	Total						
13	Field	Campaign Creek, OH	Lotic	Lepomis macrochirus	bluegill sunfish	3	Total	Total	Reject	N	The only applicable data is for arsenic in liver tissue, which is not an edible tissue.	N	N	
13	Field	Ohio River, OH	Lotic	Lepomis macrochirus	bluegill sunfish	3	Total	Total						
13	Field	Singy Run, OH	Lotic	Lepomis macrochirus	bluegill sunfish	3	Total	Total						
13	Field	Singy Run, OH	Lotic	Lepomis cyanellus	green sunfish	3	Total	Total						
13	Field	Little Scary Creek, OH	Lotic	Lepomis macrochirus	bluegill sunfish	3	Total	Total						
14	Field	20 Coastal States	Marine		shellfish	2	NM	Total	Reject	N	Water concentrations were not provided.	N	N	
15	Lab	Simulated Irrigation Drainwater	NA	Xyrauchen texanus	razorback	3	Total	NM	Reject	N	Tissue concentrations were not provided.	N	N	
15	Lab	Simulated Irrigation Drainwater	NA	Gila elegans	bonytail	3	Total	NM						
16	Field	18 Sites in Lake Xolotlan, Managua, Nicaragua	Lentic	C. citrinellum	fish	Uncertain	Total	Total	Reject	N	Tissue concentrations were given as a range from less than detect (<0.01 ug/g ww) to 0.2 to 0.4 ug/g wet weight.	N	N	
16	Field	18 Sites in Lake Xolotlan, Managua, Nicaragua	Lentic	C. managuense	fish	Uncertain	Total	Total						
17	Lab	Lab water	NA	Oncorhynchus mykiss	rainbow trout	4	NA	Total	Reject	N	Dietary exposure only.	N	N	Arsenic measured in muscle, gills, liver and skin. Concentrations were highest in the liver.
18	Field	Los Angeles Harbor (Sediment)	Marine	Genyonemus lineatus	feral fish	Uncertain	NM	Total	Reject	N	Tissue concentrations not measured.	N	N	

APPENDIX B: Summary of Arsenic Bioaccumulation Studies Reviewed															
Article #	Field or Lab	Water or Waterbody Type	Habitat Type	Species	Common Name	Trophic Level	Chemical Form Water	Chemical Form Tissue	Reject or Accept	BAF/BCF provided in paper? Y=Yes N=No	Reason for Rejection	Water Speciation Data?	Tissue Speciation Data?	Notes
19	Field	Savannah River, South Carolina	Lotic	Amia calva	bowfin		NM	Total	Reject	N	Water concentrations were not measured.	N	N	
19	Field	Savannah River, South Carolina	Lotic	Micropterus salmoides	bass	4	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Ictalurus punctatus	channel catfish	4	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Esox niger	chain pickerel	3	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Perca fluvescens	yellow perch	3	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Pomoxis	black crappie	3	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Anguilla rostrata	american eel	3	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Lepomis microlophus	shellcracker	3	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Lepomis macrochirus	bluegill	3	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Lepomis auritus	redbreast	3	NM	Total						
19	Field	Savannah River, South Carolina	Lotic	Minytrema melanops	spotted sucker	3	NM	Total						
20	Lab	Natural seawater	NA	Nereis virens	marine polychaetes	2	Arsenate	Total, Inorganic, Organic	Reject	N	No indication that steady-state was achieved. Water concentrations measured as dissolved Total Arsenic.	N	Y	12-day exposure (static). Includes speciation data in tissues.
20	Lab	Natural seawater	NA	Nereis diversicolor	marine polychaetes	2	Arsenate	Total, Inorganic, Organic						
21	Field	Ponds at Horsethief Canyon	Lentic		cladocerans and	2	NM	Total	Reject	N	Water concentrations were not provided.	N	N	Arsenic in zooplankton measured as part of dietary exposure treatment for the razorback sucker.
21	Field	Adobe Creek, CO	Lotic		cladocerans and	2	NM	Total						
21	Field	North Pond near Fruita, CO	Lentic		cladocerans and	2	NM	Total						
22	Lab	Filtered Air River water	NA	Physa fontinalis	snail	2	Arsenite	Total	Reject	N	No indication that steady-state was achieved.	N	N	10-day exposure (flow-through).
22	Lab	Filtered Air River water	NA	Asellus aquaticus	isopod	2	Arsenite	Total						
22	Lab	Filtered Air River water	NA	Gammarus fossarum	amphipod	2	Arsenite	Total						
22	Lab	Filtered Air River water	NA	Niphargus	amphipod	2	Arsenite	Total						
22	Lab	Filtered Air River water	NA	Hydropsiche pellucidula	caddisfly	2	Arsenite	Total						
22	Lab	Filtered Air River water	NA	Hepatgenia sulphurea	mayfly	2	Arsenite	Total						
23	Field	3 sites along Thane Creek, India	Lotic		phytoplankton (algae, diatoms)	1	Total Arsenic	Total	Uncertain	Y	BCF is suspect. High Total Arsenic concentrations (mean of 527 ug/L) were measured in water, but arsenic was not detected in macroinvertebrates and fish.	N	N	
24	Field	Coastal waters of Yoshimi, Shimonoseki, Japan	Marine		mixed marine organisms	1 thru 4	NM	Total	Reject	N	Water concentrations were not measured.	N	N	Tissue speciation useful for indicating differences in As species in the Marine food chain, but the arsenic species in tissues are not quantified.

APPENDIX B: Summary of Arsenic Bioaccumulation Studies Reviewed

Article #	Field or Lab	Water or Waterbody Type	Habitat Type	Species	Common Name	Trophic Level	Chemical Form Water	Chemical Form Tissue	Reject or Accept	BAF/BCF provided in paper? Y=Yes N=No	Reason for Rejection	Water Speciation Data?	Tissue Speciation Data?	Notes
25	Field	Sites in the North Sea and English Channel from Venice Lagoon	Marine		fish (25 species); shellfish	2 thru 4	NM	primarily Total	Reject	N	Water concentrations were not measured.	N	Y	Some tissue speciation data provided, divided into toxic (inorganic, MMA, DMA) and non-toxic fractions (AsB, AsC, TMAO), but the individual arsenic species are not quantified separately.
26	Field	Mine-affected and adjacent areas at Aznalcollar (Seville, Spain)	Lotic	Procambarus clarkii	freshwater crayfish	3	NM	Total, Inorganic, Organic	Reject	N	Water concentrations were not measured.	N	Y	Tissue speciation useful for indicating differences in As species in freshwater crayfish. Arsenic species in tissues are quantified.
27	Field	Puget Sound, WA	Marine		English sole	3	NM	Total, Inorganic	Reject	N	Water concentrations were not measured.	N	Y	Tissue speciation useful for indicating differences in As species in Marine fish, clams and crabs. Combined inorganic As species in tissues are quantified.
27	Field	Puget Sound, WA	Marine		quillback	3	NM	Total, Inorganic						
27	Field	Puget Sound, WA	Marine		Dungeness crab	3	NM	Total, Inorganic						
27	Field	Puget Sound, WA	Marine		coho salmon	4	NM	Total, Inorganic						
27	Field	Puget Sound, WA	Marine		Pacific herring	2	NM	Total, Inorganic						
27	Field	Puget Sound, WA	Marine		clams	2	NM	Total, Inorganic						
27	Field	Puget Sound, WA	Marine		graceful crabs	3	NM	Total, Inorganic						
28	Lab	City of Winnipeg tap water	NA		lake whitefish	3	NA	Total	Reject	N	Exposure was via diet only.	N	N	Arsenic measured in muscle and non-edible tissue. Concentrations were highest in pyloric caeca, intestine, liver, and scales.
29	Lab	Synthetic softwater	NA	Monoraphidium	freshwater	1	Arsenate	Inorganic, Organic	Reject	N	No indication that steady-state was achieved.	N	Y	72-h exposure (static). Tissue As speciation measured at IC50 concentrations (high).
29	Lab	Synthetic softwater	NA	Chlorella sp.	freshwater	1	Arsenate	Inorganic, Organic						
30	Lab	Sea water		Crangon crangon	shrimp	2	Arsenate	Total	Reject	N	Data did indicate that steady-state was achieved after 8 days. Concentrations of As species in water were not measured.	Y	N	10-day static renewal exposure.
30	Lab	Sea water		Crangon crangon	shrimp	2	TMAO	Total						
30	Lab	Sea water		Crangon crangon	shrimp	2	AB	Total						
31	Lab	Modified Detmer medium		Chlorella vulgaris	freshwater algae	1	Arsenate	Total, Inorganic, Organic	Reject	N	No indication that steady-state was achieved.	N	Y	7-day exposure (static). Does include speciation in tissue from wateborne and dietary exposure (lab food chain study). No indication of biomagnification.
31	Lab	Modified Detmer medium		Phormidium sp.	freshwater algae	1	Arsenate	Total, Inorganic, Organic						
31	Lab	Modified Detmer medium		Moina macrocopa	zooplankton	2	Arsenate	Total, Inorganic, Organic						
31	Lab	Modified Detmer medium		Poecila reticulata	guppy fish	3	Arsenate	Total, Inorganic, Organic						
32	Lab	Modified Detmer medium		Cyprinus carpio	carp	3	Arsenate	Total, Inorganic, Organic	Reject	N	No indication that steady-state was achieved. Water Arsenate concentrations not measured.	N	Y	7-day exposure (static). Does include speciation in tissue from wateborne and dietary exposure (lab food chain study). No indication of biomagnification. Arsenic species measured in muscle, gut, and skin. Total As concentrations were highest in the gut.
33	Lab	Modified Detmer medium		Neocaridina denticulata	shrimp	2	Arsenate	Total, Inorganic, Organic	Reject	N	No indication that steady-state was achieved. Water Arsenate concentrations not measured.	N	Y	7-day exposure (static). Does include speciation in tissue from wateborne and dietary exposure (lab food chain study). No indication of biomagnification. Biomethylation increases with trophic level.
34	Lab	Sand filtered sea water		Mytilus edulis	mussels	2	AsB 1,2,3	Total	Reject	N	No indication that steady-state was achieved.	N	Y	10-day exposure (static). Water AsB concentrations were confirmed with measurement. Order of AsB uptake efficieny is the following AsB1 > AsB2> AsB3.
34	Lab	Sand filtered sea water		Mytilus edulis	mussels	2	AsB 1,2,3	AsB						

APPENDIX B: Summary of Arsenic Bioaccumulation Studies Reviewed

Article #	Field or Lab	Water or Waterbody Type	Habitat Type	Species	Common Name	Trophic Level	Chemical Form Water	Chemical Form Tissue	Reject or Accept	BAF/BCF provided in paper? Y=Yes N=No	Reason for Rejection	Water Speciation Data?	Tissue Speciation Data?	Notes
35	Field	Mouth of Miami River, Biscayne	Estuarine	Isognomon sp. -	mussels	2	Dissolved	Total, Inorganic,	Accept	N		Y	N	
35	Field	Mouth of Miami River, Biscayne	Estuarine	Crassostrea virginica	oysters	2	Dissolved	Total, Inorganic,						
36	Field	Electric utility wastewater	Lentic	Cyprinus carpio	common carp	3	Total	Total	Accept	N		N	N	
37	Field	Restronguet Creek in Fal Estuary,	Estuarine	Scrobicularia plana	bivalve	2	Dissolved	Total	Accept	Y (3882)		N	N	
37	Field	Tamar Estuary, SW England	Estuarine	Scrobicularia plana	bivalve	2	Dissolved	Total	Accept	Y (3110)				
38	Field	Devil's Swamp, lower Mississippi	Lotic /	33 species	freshwater fish	3-4	Total	Total	Accept	N		N	N	
38	Field	Tunica Swamp, lower Mississippi	Lotic /	28 species	freshwater fish	3-4	Total	Total	Accept	N				
39	Field	Hypersaline evaporation ponds, CA	Saltwater	Artemia franciscana	brine shrimp	2	Total Arsenic	Total	Reject	N	Data are for brine shrimp. Water [As] was measured in samples collected December 1995, but corresponding [As] in adult brine shrimp weren't collected for analysis until August 1996.	N	N	
40	Field	Hayakawa River, Japan	Lotic	13 FW species	an alga, diatom, invertebrates and fishes	1-4	Total Arsenic	Total, Inorganic, Organic	Accept	N		N	N	
41	Lab	Sea water	NA	Mytilus edulis	blue mussel	2		Total, Organic	Reject	N		N	N	
42	Field	Venetian Lagoon, Island of	Marine	Mytilus galloprovincialis	mussell	2	Dissolved	Total	Accept	N		N	N	
43	Lab	Narragansett Bay seawater	NA	Crassostrea virginica	eastern oyster	2	Total	Total	Reject	N		N	N	
44	Field	Grace Lake, NW Territories,	Lotic		zooplankton &	2	Dissolved	Total	Accept	Y		N	N	
44	Field	Grace Lake, NW Territories,	Lotic	Cottus cognatus	sculpin	3	Dissolved	Total	Accept	Y				
44	Field	Kam Lake, NW Territories,	Lotic		zooplankton &	2	Dissolved	Total	Accept	Y				
44	Field	Kam Lake, NW Territories,	Lotic	Cottus cognatus	sculpin	3	Dissolved	Total	Accept	Y				
45	Field	San Francisco and Upper Gila	Lotic	Ictalurus punctatus	channel catfish	3	Total	Total	Accept	N		N	N	
45	Field	San Francisco and Upper Gila	Lotic	Pilodictis olivaris	flathead catfish	3	Total	Total	Accept	N				
45	Field	Upper Gila River, AZ	Lotic	Cyprinus carpio	common carp	2	Total	Total	Accept	N				
45	Field	Upper Gila River, AZ	Lotic	Micropterus salmoides	largemouth bass	4	Total	Total	Accept	N				

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46	Field	Blacklick Run and Herrington	Lotic	Crustacea	crayfish	3	Dissolved	Total	Accept	N		N	N	
46	Field	Blacklick Run and Herrington	Lotic	cranefly, caddisfly,	invertebrates	2-3	Dissolved	Total	Accept	N				
46	Field	Blacklick Run and Herrington	Lotic	Ameirus nebulosus	brown bullhead	3	Dissolved	Total	Accept	N				
46	Field	Blacklick Run and Herrington	Lotic	Catostomus	white sucker	3	Dissolved	Total	Accept	N				
46	Field	Blacklick Run and Herrington	Lotic	Cottus bairdi	mottled sculpin	3	Dissolved	Total	Accept	N				
46	Field	Blacklick Run and Herrington	Lotic	Rhinichthys atratulus	blacknose dace	3	Dissolved	Total	Accept	N				
46	Field	Blacklick Run and Herrington	Lotic	Semotilus	creek chub	4	Dissolved	Total	Accept	N				
46	Field	Blacklick Run and Herrington	Lotic	Salvelinus fontinalis	brook trout	4	Dissolved	Total	Accept	Y				
47	Field	Fish ponds, southwest coast of	Estuarine	Liza macrolepis	mullet		Total	Total	Accept	N		N	N	
48	Field	20 Lakes in NW U.S.	Lentic		zooplankton	2	Dissolved	Total	Accept	N		N	N	
48	Field	20 Lakes in NW U.S.	Lentic		piscivorous and omnivorous fish	3-4	Dissolved Arsenic	Total	Accept	Y				
49	Field	Moon lake, Mississippi	Lentic		benthivorous	3	Total	Total	Accept	N		N	N	
49	Field	Moon lake, Mississippi	Lentic		omnivorous fish	3	Total	Total	Accept	N				
49	Field	Moon lake, Mississippi	Lentic		planktivorous	2	Total	Total	Accept	N		N	N	
50	Field	Upper Mystic Lake, MA	Lentic		zooplankton	2	Dissolved	Total	Accept	N		N	N	
50	Field	Upper Mystic Lake, MA	Lentic		alewife	3	Dissolved	Total	Accept	N				
50	Field	Upper Mystic Lake, MA	Lentic		Killifish	3	Dissolved	Total	Accept	N				
50	Field	Upper Mystic Lake, MA	Lentic	Pomoxis	black crappie	3	Dissolved	Total	Accept	N				
50	Field	Upper Mystic Lake, MA	Lentic	Lepomis macrochirus	bluegill sunfish	3	Dissolved	Total	Accept	N				
50	Field	Upper Mystic Lake, MA	Lentic	Micropterus salmoides	largemouth bass	4	Dissolved	Total	Accept	N				
50	Field	Upper Mystic Lake, MA	Lentic	Perca flavescens	yellow perch	3	Dissolved	Total	Accept	N				

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Article #	Field or Lab	Water or Waterbody Type	Habitat Type	Species	Common Name	Trophic Level	Chemical Form Water	Chemical Form Tissue	Reject or Accept	BAF/BCF provided in paper? Y=Yes N=No	Reason for Rejection	Water Speciation Data?	Tissue Speciation Data?	Notes
51	Lab	Filtered Lake Superior water	NA	Pteronarcys dorsata	stonefly	2	Arsenite	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Pteronarcys dorsata	stonefly	2	Arsenate	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Pteronarcys dorsata	stonefly	2	DMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Pteronarcys dorsata	stonefly	2	MMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Helisoma campanulata	snail	2	Arsenite	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Helisoma campanulata	snail	2	Arsenate	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Helisoma campanulata	snail	2	DMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Helisoma campanulata	snail	2	MMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Stagnicola emarginata	snail	2	Arsenite	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Stagnicola emarginata	snail	2	Arsenate	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Stagnicola emarginata	snail	2	DMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Stagnicola emarginata	snail	2	MMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Daphnia magna	cladoceran	2	Arsenite	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Daphnia magna	cladoceran	2	Arsenate	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Daphnia magna	cladoceran	2	DMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Daphnia magna	cladoceran	2	MMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Gammarus	amphipod	2	Arsenite	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Gammarus	amphipod	2	Arsenate	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Gammarus	amphipod	2	DMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Gammarus	amphipod	2	MMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Oncorhynchus mykiss	rainbow trout	4	Arsenite	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Oncorhynchus mykiss	rainbow trout	4	Arsenate	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Oncorhynchus mykiss	rainbow trout	4	DMA	Total	Accept	N		N	N	
51	Lab	Filtered Lake Superior water	NA	Oncorhynchus mykiss	rainbow trout	4	MMA	Total	Accept	N		N	N	
52	Lab	Well water	NA	Lepomis macrochirus	bluegill sunfish	3	Arsenite	Total	Accept	Y	Authors state that it appeared that steady-state was not achieved over the 4 wk exposure period; This data was used in the 1985 Arsenic AWQC document, so it was included for comparison.	N	N	

APPENDIX B: Articles Reviewed			
Article #	Authors	Year	Reference
1	Suhendrayatna et al.	2001	Applied Organometallic Chemistry 15:277-284.
2	Goessler et al.	1997	Fresenius Journal of Analytical Chemistry 359:434-437.
3	Suhendrayatna et. al.	2002	Chemosphere 46:319-324.
4	Suhendrayatna et. al.	2002	Chemosphere 46:325-331.
5	Goldstein and DeWeese.	1999	Journal of the American Water Resources Association 35(5):1133-1140.
6	Barrows et al.	1980	In: Dynamics, Exposure and Hazard Assessment of Toxic Chemicals. Ann Arbor Science Pub., Inc., Ann Arbor, MI
7	Jackson et al.	2002	Analytical and Bioanalytical Chemistry 374:203-211.
8	Ochsenkuhn-Petropulu et al.	1997	Analytica Chimica Acta 337:323-327.
9	Hung et al.	2001	Chemosphere 44:833-841.
10	King et al.	1997	Environmental contaminants in fish and wildlife of the lower Gila River, Arizona. US Fish & Wildlife Service, pp. 1-70.
11	King et al.	1999	Contaminants as a limiting factor of fish and wildlife populatios in the Santa Cruz River, Arizona. US Fish & Wildlife Service, pp. 1-56
12	King and Baker.	1995	Contaminants in fish and wildlife of the Middle Gila River, Arizona. US Fish & Wildlife Service, pp 1-17.
13	Lohner et al.	2001	Ecotoxicology and Environmental Safety 50:203-216.
14	United States Food and Drug Administration.	1993	Guidance Document for Arsenic in Shellfish, pp. 1-27.
15	Hamilton et al.	2000	Environmental Toxicology 15:48-64
16	Lacayo et al.	1992	Bulletin of Environmental Contamination and Toxicology 49:463-470.
17	Oladimejei et al.	1984	Bulletin of Environmental Contamination and Toxicology 32:732-741.
18	Anderson et al.	2002	Environmental Toxicology and Chemistry 20(2):359-370.
19	Burger et al.	2002	Environmental Research Section A 89:85-97.
20	Geiszinger et al.	2002	Environmental Science and Technology 36:2905-2910.
21	Hamilton et al.	2002	Aquatic Toxicology 59:253-281.

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Article #	Authors	Year	Reference
22	Canivet et al.	2001	Archives of Environmental Contamination and Toxicology 40:345-354.
23	Athalye et al.	2001	Ecology, Environment and Conservation 7(3):319-325.
24	Hanaoka et. al.	1988	Applied Organometallic Chemistry 2:371-376.
25	De Gieter et al.	2002	Archives of Environmental Contamination and Toxicology 43:406-417.
26	Devesa et al.	2002	Applied Organometallic Chemistry 16:123-132.
27	Johnson and Roose.	2002	Report for the Environmental Assessment Program, Olympia, Washington. Pub. No. 02-03-057
28	Pedlar and Klaverkamp.	2002	Aquatic Toxicology 57:153-166.
29	Strauber et al.	2002	23rd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Poster and Absract No. P296.
30	Hunter and Goessler.	1998	Marine Biology 131:543-552.
31	Maeda et al.	1990	Applied Organometallic Chemistry 4:251-254.
32	Maeda et al.	1993	Applied Organometallic Chemistry 7:467-476.
33	Maeda et al.	1992	Applied Organometallic Chemistry 6:213-219.
34	Francesconi et al.	1999	Comparative Biochemistry and Physiology Part C 122:131-137.
35	Valette-Silver et al.	1999	Marine Environmental Research 48:311-333.
36	Skinner	1985	Proceedings of the Pennsylvania Academy of Science 59:155-161.
37	Langston	1984	Marine Biology 80:143-154.
38	Bart et al.	1998	Ecotoxicology 7:325-334.
39	Tanner et al.	1999	Water Environment Research 71(4):494-505.
40	Kaise et al.	1997	Applied Organometallic Chemistry 11:297-304.
41	Gailer et al.	1995	Applied Organometallic Chemistry 9:341-355.
42	Giusti and Zhang.	2002	Environmental Geochemistry and Health 24:47-65.
43	Zaroogian and Hoffman.	1982	Environmental Monitoring and Assessement 1:345-358.
44	Wagemann et al.	1978	Archives of Environmental Contamination and Toxicology 7:169-191.

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Article #	Authors	Year	Reference
45	Baker and King.	1994	Environmental contamination investigations of water quality, sediment, and biota of the upper Gila River Basin, Arizona. US Fish & Wildlife Service,
46	Mason et al.	2000	Archives of Environmental Contamination and Toxicology 38:283-297.
47	Lin et al.	2001	Bulletin of Environmental Contamination and Toxicology 67:91-97.
48	Chen et al.	2000	Limnology and Oceanography 45(7):1525-1536.
49	Cooper and Gillespie.	2001	Environmental Pollution 111:67-74.
50	Chen and Folt.	2000	Environmental Science and Technology 34:3878-3884.
51	Spehar et al.	1980	Archives of Environmental Contamination and Toxicology 9:53-63
52	Barrows et al.	1980	In: R. Hague (ed.) Dyanmics, Exposure, and Hazard Assessment of Toxic Chemicals. Ann Arbor Sci., Ann Arbor, MI

APPENDIX C

BCF STUDIES: RAW DATA AND CALCUATIONS

APPENDIX C: BCF Studies

Gailer et al. 1995. Applied Organometallic Chemistry 9:341-355

10-day static-renewal exposure of different arsenic compounds to Mytilus edulis

Note: arsenate, dimethylarsenic acid, dimethyl(2-hydroxyethyl)arsine oxide, trimethylarsine oxide, arsenite and methylarsonic acid were also exposed to Mytilus at 0.1 mg/L, but did not accumulate in tissues more than the control.

Arsenic cmpd used in exposure	Species	Common name	Cw mg/L*	Ct mg/kg**	BCF
arsenobetaine	Mytilus edulis		0.1	139	1390
trimethylarsonium iodide	Mytilus edulis		0.1	15.1	151
arsenocholine	Mytilus edulis		0.1	45.4	454
			* nominal concentration	** wet weight whole animal	

Hunter and Goessler 1998. Marine Biology. 131:543-552

24-day static-renewal exposure of different arsenic compounds to the common shrimp, Crangon crangon

Note: arsenate and trimethylarsine oxide were also exposed to the shrimp but were not accumulated

Arsenic cmpd used in exposure	Species	Common name	Cw mg/L*	Ct mg/kg**	Ct mg/kg***	BCF dry weight	BCF wet weight
arsenobetaine	Crangon crangon		0.108	18.8	3.76	174.07	35
			* measured concentration	** dry weight tail muscle	*** converted to wet weight assuming 80% water content		

Maeda, et al. 1990. Applied Organometallic Chemistry. 4:251-254

7-day static exposure (not specified in paper) of different Na2HAsO4 to the zooplankter, Moina macrocopa and the guppy, Poecilia reticulata

Note: only one data point on day 7, therefore it is not known if steady-state has been achieved

Nominal concentration of Na2HAsO4 used in exposure, mg/L	Species	Common name	Cw mg/L*	Total As Ct mg/kg**	Total As Ct mg/kg***	Inorganic As Ct mg/kg**	Mono-CH3 Ct mg/kg**	Di-CH3 Ct mg/kg**	Tri-CH3 Ct mg/kg**	Total As BCF dry weight	Total As BCF wet weight
1	Moina		0.403	4.7	0.94	2.1	trace	2.6	trace	11.66	2
0.5	Poecilia		0.2015	6.8	1.7	5	0.6	0.1	1.1	33.75	8
1	Poecilia		0.403	6.9	1.725	5.8	0.1	0.2	0.8	17.12	4
10	Poecilia		4.03	40	10	30.6	5.9	0.7	2.8	9.93	2
										Geomean	4
			*conc'n as As, based on 0.403 of 186 MW	** dry weight	*** converted to wet weight assuming 80% water content for Moina, and 75% for Poecilia						

APPENDIX C: BCF Studies

Maeda, et al. 1993. Applied Organometallic Chemistry. 7:467-476

7-day static exposure (not specified in paper) of different Na2HAsO4*7H20 (As(V)) to the carp, Cyprinus carpio. Note: only one data point on day 7, therefore it is not known if steady-state has been achieved

MUSCLE

Nominal concentration of As(V), mg/L	Species	Common name	Total As Ct mg/kg**	Total As Ct mg/kg***	Non-methylated As Ct mg/kg**	Mono-CH3 Ct mg/kg**	Di-CH3 Ct mg/kg**	Tri-CH3 Ct mg/kg***	Total As BCF dry weight	Total As BCF wet weight
0	Cyprinus		2	0.4	1.8			0.2		
10	Cyprinus		3.8	0.76	3.6	trace	trace	0.2	0.38	0.08
20	Cyprinus		6	1.2	5	0.4	0.2	0.4	0.30	0.06
30	Cyprinus		5.8	1.16	4.6	0.2	0.1	0.9	0.19	0.04
40	Cyprinus		7.2	1.44	6	0.5	0.3	0.4	0.18	0.04
50	Cyprinus		11.4	2.28	7	3.1	0.6	0.7	0.23	0.05
60	Cyprinus		12	2.4	7.1	2.5	1	1.4	0.20	0.04
			** dry weight in muscle tissue						Geomean	0.048

GUT

Nominal concentration of As(V), mg/L	Species	Common name	Total As Ct mg/kg**	Total As Ct mg/kg***	Non-methylated As Ct mg/kg**	Mono-CH3 Ct mg/kg**	Di-CH3 Ct mg/kg**	Tri-CH3 Ct mg/kg***	Total As BCF dry weight	Total As BCF wet weight
0	Cyprinus		7.6	1.52	7.3		0.2	0.1		
10	Cyprinus		19.7	3.94	15	3.8	0.6	0.3	1.97	0.39
20	Cyprinus		23.8	4.76	16	4.8	1.4	1.9	1.19	0.24
30	Cyprinus		40	8	13	24	1.4	1.6	1.33	0.27
40	Cyprinus		51.4	10.28	17	29	3.4	2	1.28	0.26
50	Cyprinus		60.6	12.12	20	36	3.1	1.5	1.21	0.24
60	Cyprinus		82.8	16.56	22	57	1.5	2.3	1.38	0.28
			** dry weight in gut						Geomean	0.275

CARP REMNANTS (SKIN, SCALE, BONE, FIN)

Nominal concentration of As(V), mg/L	Species	Common name	Total As Ct mg/kg**	Total As Ct mg/kg***	Non-methylated As Ct mg/kg**	Mono-CH3 Ct mg/kg**	Di-CH3 Ct mg/kg**	Tri-CH3 Ct mg/kg***	Total As BCF dry weight	Total As BCF wet weight
0	Cyprinus		5.5	1.1	5.4		0.1	trace		
10	Cyprinus		7.5	1.5	6.5	0.3	0.1	0.6	0.75	0.15
20	Cyprinus		7.9	1.58	6.7	0.4	0.2	0.6	0.40	0.08
30	Cyprinus		6.7	1.34	5.2	0.5	0.2	0.8	0.22	0.04
40	Cyprinus		6.8	1.36	5	0.5	0.4	0.9	0.17	0.03
50	Cyprinus		13.8	2.76	9.2	2.7	0.7	1.2	0.28	0.06
60	Cyprinus		12.6	2.52	9	1.8	0.5	1.3	0.21	0.04

** dry weight	*** converted to wet weight assuming 80% water content	Geomean	0.059

APPENDIX C: BCF Studies

Maeda, et al. 1992. Applied Organometallic Chemistry. 6:213-219

7-day static exposure (not specified in paper) of different Na2HAsO4 (As V) to the shrimp, Neocaridina denticulata

Note: only one data point on day 7, therefore it is not known if steady-state has been achieved

Nominal concentration of Na2HAsO4 (as As V) used in exposure, mg/L	Species	Common name	Total As Ct mg/kg**	Total As Ct mg/kg***	Inorganic As Ct mg/kg**	Mono-CH3 Ct mg/kg**	Di-CH3 Ct mg/kg**	Tri-CH3 Ct mg/kg**	Total As BCF dry weight	Total As BCF wet weight
0.1	Neocardia		18.9	3.78	15.9		1.9	1.1	189	38
0.2	Neocardia		18.5	3.7	14.9	trace	1.9	1.7	92	18
0.3	Neocardia		19.8	3.96	17.3		1.4	1.1	66	13
0.5	Neocardia		22.6	4.52	15.4	trace	2.6	4.6	45	9
1	Neocardia		33.2	6.64	30.2	trace	1.7	1.3	33	7
1.5	Neocardia		31.6	6.32	27.9	trace	2.2	1.5	21	4
			** dry weight	*** converted to wet weight assuming 80% water content					Geomean	12

Francesconi et al. 1999. Comparative Biochemistry and Physiology Part C 122:131-137

10-day static exposure of arsenic-betaines to the mussel, Mytilus edulis

Note: only one data point on day 10, therefore it is not known if steady-state has been achieved

Nominal concentration of As-betaine used in exposure, mg/L*	Species	Common name	Total As Ct mg/kg**	Total As Ct mg/kg***	Total As BCF dry weight	Total As BCF wet weight
control	Mytilus		18.3	3.66	NA	
0.1 C-1 betaine	Mytilus		1740	348	17217	3443
0.1 C-2 betaine	Mytilus		1220	244	12017	2403
0.1 C-3 betaine	Mytilus		151	30.2	1327	265
*nominal concentrations were confirmed with measurements - all within 4%			** dry weight	*** converted to wet weight assuming 80% water content	Geomean	1300

Zaroogian and Hoffman. 1982. Environmental Monitoring and Assessment 1:345-358

16 week study flow-through exposure of arsenic as arsenite to eastern oysters, Crassostrea virginica

Note: uptake initially increased in the first 5 weeks, then decreased with spawning, followed by a subsequent increase again. Steady-state is never really achieved.

Nominal concentration of Na2HAsO4 (as As III) used in exposure, mg/L	Species	Common name	Total As Cw mg/L	Total As Ct mg/kg**	Total As Ct mg/kg***	Total As BCF dry weight	Total As BCF wet weight
control	Crassostrea		0.0012	10.3	2.06	8583	1717
3	Crassostrea		0.0033	12.7	2.54	3848	770
5	Crassostrea		0.0058	14.1	2.82	2431	486
				** dry weight	*** converted to wet weight assuming 80% water content		

APPENDIX C: BCF Studies

Langston. 1984. Marine Biology. 80:143-154

10-day renewal exposure of native Scrobicularia plana (3 cm length) from Restronguet Creek and Tamar Estuary, U.K.

Dry Weight Basis	Species	common name	Dissolved As Cw mg/L*	Total As Ct mg/kg**	Total As Ct mg/kg***	Total As BCF dry weight	Total As BCF wet weight
	Scrobicularia plana	bivalve	0.01	0.784	0.124656	78	12
			* Interstitial water As concentrations	** dry weight of total soft parts	** converted to wet weight based on a water content of 84.1%		

Spehar et al. 1980. Archives of Environmental Contamination and Toxicology. 9:53-63.

28-day intermittent flow exposure (100% renewal every 9 hrs) of wild-caught invertebrates and hatchery-reared rainbow trout parr

Original whole body tissue arsenic concentrations reported on a dry weight basis; converted to wet wt assuming 80% water content for invertebrates, and 75% for fish.

Nominal concentration of As2O3 (As(III) used in exposure, mg/L	Species	Common name	Total As Cw mg/L*	Total As Ct mg/kg*	Total As Ct mg/kg wet wt	Total As BAF dry weight	Total As BAF wet weight	Geomean
100	Pteronarcys dorsata	stonefly	0.088	NA				9
1000	Pteronarcys dorsata	stonefly	0.961	42	8.4	44	9	
100	Daphnia magna	cladoceran	0.088	21	4.2	239	48	22
1000	Daphnia magna	cladoceran	0.961	47	9.4	49	10	
100	Helisoma campanulata	snail	0.088	2.5	0.5	28	6	10
1000	Helisoma campanulata	snail	0.961	80	16	83	17	
100	Stagnicola emarginata	snail	0.088	3.3	0.66	38	8	5
1000	Stagnicola emarginata	snail	0.961	16	3.2	17	3	
100	Gammurus pseudolimnaeus	amphipod	0.088					
1000	Gammurus pseudolimnaeus	amphipod	0.961					
100	Oncorhynchus mykiss	rainbow trout	0.088					
1000	Oncorhynchus mykiss	rainbow trout	0.961					
			* Measured as total As in water					

APPENDIX C: BCF Studies

Spehar et al. 1980. Archives of Environmental Contamination and Toxicology. 9:53-63.

28-day intermittent flow exposure (100% renewal every 9 hrs) of wild-caught invertebrates and hatchery-reared rainbow trout parr

Original whole body tissue arsenic concentrations reported on a dry weight basis; converted to wet wt assuming 80% water content for invertebrates, and 75% for fish.

Nominal concentration of 3As2O5 .5H2O (As(V) used in exposure, mg/L	Species	Common name	Total As Cw mg/L*	Total As Ct mg/kg*	Total As Ct mg/kg wet wt	Total As BAF dry weight	Total As BAF wet weight	Geomean
100	Pteronarcys dorsata	stonefly	0.089	12	2.4	135	27	14
1000	Pteronarcys dorsata	stonefly	0.973	34	6.8	35	7	
100	Daphnia magna	cladoceran	0.089	5.2	1.04	58	12	7
1000	Daphnia magna	cladoceran	0.973	19	3.8	20	4	
100	Helisoma campanulata	snail	0.089	8.8	1.76	99	20	10
1000	Helisoma campanulata	snail	0.973	27	5.4	28	6	
100	Stagnicola emarginata	snail	0.089	8.2	1.64	92	18	8
1000	Stagnicola emarginata	snail	0.973	17	3.4	17	3	
100	Gammurus pseudolimnaeus	amphipod	0.089					
1000	Gammurus pseudolimnaeus	amphipod	0.973					
100	Oncorhynchus mykiss	rainbow trout	0.089					
1000	Oncorhynchus mykiss	rainbow trout	0.973					

* Measured as total As in water

Spehar et al. 1980. Archives of Environmental Contamination and Toxicology. 9:53-63.

28-day intermittent flow exposure (100% renewal every 9 hrs) of wild-caught invertebrates and hatchery-reared rainbow trout parr

Original whole body tissue arsenic concentrations reported on a dry weight basis; converted to wet wt assuming 80% water content for invertebrates, and 75% for fish.

Nominal concentration of (CH3)2AsO(ONa) SDMA used in exposure, mg/L	Species	Common name	Total As Cw mg/L*	Total As Ct mg/Kg*	Total As Ct mg/Kg wet wt	Total As BAF dry weight	Total As BAF wet weight	Geomean
100	Pteronarcys dorsata	stonefly	0.086	2.4	0.48	28	6	6
1000	Pteronarcys dorsata	stonefly	0.97	29	5.8	30	6	
100	Daphnia magna	cladoceran	0.086	7.2	1.44	84	17	9
1000	Daphnia magna	cladoceran	0.97	23	4.6	24	5	
100	Helisoma campanulata	snail	0.086	1.9	0.38	22	4	5
1000	Helisoma campanulata	snail	0.97	23	4.6	24	5	
100	Stagnicola emarginata	snail	0.086	NA				2
1000	Stagnicola emarginata	snail	0.97	9.8	1.96	10	2	
100	Gammurus pseudolimnaeus	amphipod	0.086					
1000	Gammurus pseudolimnaeus	amphipod	0.97					
100	Oncorhynchus mykiss	rainbow trout	0.086					
1000	Oncorhynchus mykiss	rainbow trout	0.97					

* Measured as total As in water

APPENDIX C: BCF Studies

Spehar et al. 1980. Archives of Environmental Contamination and Toxicology. 9:53-63.

28-day intermittent flow exposure (100% renewal every 9 hrs) of wild-caught invertebrates and hatchery-reared rainbow trout parr

Original whole body tissue arsenic concentrations reported on a dry weight basis; converted to wet wt assuming 80% water content for invertebrates, and 75% for fish.

Nominal concentration of CH32AsO(ONa)2.6H2O DSMA used in exposure, mg/L	Species	Common name	Total As Cw mg/L*	Total As Ct mg/Kg*	Total As Ct mg/Kg wet wt	Total As BAF dry weight	Total As BAF wet weight	Geomean
100	Pteronarcys dorsata	stonefly	0.085	1.8	0.085	2	0	7
1000	Pteronarcys dorsata	stonefly	0.846	44	8.8	52	10	
100	Daphnia magna	cladoceran	0.085	5	1	59	12	7
1000	Daphnia magna	cladoceran	0.846	17	3.4	20	4	
100	Helisoma campanulata	snail	0.085	2.6	0.52	31	6	5
1000	Helisoma campanulata	snail	0.846	18	3.6	21	4	
100	Stagnicola emarginata	snail	0.085	1	0.2	12	2	3
1000	Stagnicola emarginata	snail	0.846	16	3.2	19	4	

APPENDIX D
BAF STUDIES: RAW DATA AND CALCULATIONS

BAF Studies

Skinner. 1985. Proceedings of the Pennsylvania Academy of Science. 59:155-161

Scope: measurements of contaminants in fish and water in fly ash basins (As BAF)

Dry Weight Basis

Location	Species	Common Name	Cw mg/L*	Ct mg/kg**	BAF dry weight	log BAF	Avg log BAF per Location	Avg BAF per Location
BI#6		carp	0.03	0.3	10.0	1.0	1.00	10.0
Mon FA		carp	0.016	0.7	43.7	1.6	1.64	43.8
Mon DB		carp	0.003	0.9	300.0	2.5		
Mon DB		carp	0.003	0.8	266.7	2.4	2.45	282.8
Mon SW		carp	0.003	0.2	66.7	1.8		
Mon SW		carp	0.003	0.2	66.7	1.8	1.82	66.7
MC IWTB		carp	0.006	0.5	83.3	1.9		
MC IWTB		carp	0.006	0.7	116.7	2.1		
MC IWTB		carp	0.006	0.5	83.3	1.9	1.97	93.2
			*Total As	**Total As, dry weight edible				

Wet Weight Basis

Location	Species	Common Name	Cw mg/L*	Ct mg/kg***	BAF dry weight	log BAF	Avg log BAF per Location	Avg BAF per Location
BI#6		carp	0.03	0.06	2.0	0.3	1.00	10.0
Mon FA		carp	0.016	0.14	8.7	0.9	0.94	8.8
Mon DB		carp	0.003	0.18	60.0	1.8		
Mon DB		carp	0.003	0.16	53.3	1.7	1.75	56.6
Mon SW		carp	0.003	0.04	13.3	1.1		
Mon SW		carp	0.003	0.04	13.3	1.1	1.12	13.3
MC IWTB		carp	0.006	0.1	16.7	1.2		
MC IWTB		carp	0.006	0.14	23.3	1.4		
MC IWTB		carp	0.006	0.1	16.7	1.2	1.27	18.6
			*Total As	*** converted to wet weight assuming 80%				

BAF Studies

Kaise et al. 1997. Applied Organometallic Chemistry. 11:297-304

Scope: As species in water, algae, macroinvertebrates and fish collected from the Hayakawa River (Japan)

Location	Species	Common Name	Total As Cw mg/L*	Total As Ct mg/kg*	Inorganic As Ct mg/kg*	Methylarsine Ct mg/kg*	Diemthylarsine Ct mg/kg*	Trimethylarsine Ct mg/kg*	Total As BAF
Hayakawa River (Japan)	*Clodophora glomerata*	green alga	0.03	0.453	0.0	ND	0.385	0.015	15.1
Hayakawa River (Japan)	*Diatom*	FW Diatom	0.03	0.124	0.0	ND	0.101	0.003	4.1
Hayakawa River (Japan)	*Plecoglossus altivelis*	sweet fish	0.03	0.051	ND	ND	0.005	0.040	1.7
Hayakawa River (Japan)	*Onchorhynchus masou masou*	masu salmon	0.03	0.146	ND	ND	0.063	0.081	4.9
Hayakawa River (Japan)	*Rhinogobius sp.*	goby	0.03	0.333	ND	ND	0.077	0.238	11.1
Hayakawa River (Japan)	*Phoxinus steindachneri*	downstream fatminnow	0.03	0.267	ND	ND	0.061	0.197	8.9
Hayakawa River (Japan)	*Trobolodon hakonensis*	Japanese dace	0.03	0.100	ND	ND	0.076	0.020	3.3
Hayakawa River (Japan)	*Sicyopterus japonicus*	amphidromous goby	0.03	0.370	ND	ND	0.089	0.269	12.3
Hayakawa River (Japan)	*Macrobranchiura nipponense*	prawn	0.03	0.817	ND	ND	0.614	0.187	27.2
Hayakawa River (Japan)	*Semisulcospira libertina*	marsh snail	0.03	0.186	ND	ND	0.050	0.116	6.2
Hayakawa River (Japan)	*Plotohermes grandis*	dobsonfly larva	0.03	2.875	ND	ND	2.762	0.043	95.8
Hayakawa River (Japan)	caddisfly larva	caddisfly larva	0.03	0.236	ND	ND	0.202	0.022	7.9
Hayakawa River (Japan)	*Stenopsyche marmorata*	caddisfly pupa	0.03	2.050	ND	ND	1.180	0.839	68.3

*wet weight

Bart et al. 1998. Ecotoxicology. 7:325-334

Scope: Total As in fish and water from the lower Mississippi River

Location	Species	Common Name	Total As Cw mg/L*	Total As Ct mg/kg*	Total As BAF
Devil's Swamp	mean of numerous spp.		0.147	0.061	0.4
Tunica Swamp	mean of numerous spp.		0.221	0.035	0.2

*assumed to be wet weight (not stated) based on the article's stating of dry wt for sediment samples with no reference to fish

BAF Studies

Valette-Silver et al. 1999. Marine Environmental Research. 48:311-333

Scope: As data from National Status and Trends program (1986-1995)

Dry Weight Basis

Location	Species	Common Name	Total As Cw mg/L*	As(III) Cw mg/L**	As(V) Cw mg/L**	MMA Cw mg/L**	DMA Cw mg/L**	Total As Ct mg/kg**	Total As BAF dry weight
Miami River mouth	*Isognomon sp.-radiatus?*	bivalve	0.00089	0.0	0.00069	0.00003	0.00006	37.3	41910
Miami River mouth	*Crassostrea virginica*	bivalve	0.00089	0.0	0.00069	0.00003	0.00006	23.6	26517

* water samples were filtered ** dry weight

Wet Weight Basis

Location	Species	Common Name	Total As Cw mg/L*	As(III) Cw mg/L**	As (V) Cw mg/L**	MMA Cw mg/L**	DMA Cw mg/L**	Total As Ct mg/kg***	Total As BAF wet weight
Miami River mouth	*Isognomon sp.-radiatus?*	bivalve	0.00089	0.0	0.00069	0.00003	0.00006	7.46	8382
Miami River mouth	*Crassostrea virginica*	bivalve	0.00089	0.0	0.00069	0.00003	0.00006	4.72	5303

* water samples were filtered *** converted to wet weight assuming 80% water content

Langston. 1984. Marine Biology. 80:143-154

Scope: In field study, measued Total As in the bivalve mollusk, Scrobicularia plana and in Restronguet Creek

Dry Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L*	Total As Ct mg/kg**	Total As BAF
Restronguet Creek, Site S	*Scrobicularia plana*	bivalve	0.0049	200.0	40816.3
Restronguet Creek*	*Scrobicularia plana*	bivalve	0.0551	214.0	3883.8
Tamar Estuary*	*Scrobicularia plana*	bivalve	0.0109	34.0	3119.3

* Interstitial water As concentrations ** dry weight of Total soft parts

Wet Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L*	Total As Ct mg/kg**	Total As BAF
Restronguet Creek, Site S	*Scrobicularia plana*	bivalve	0.0049	31.8	6489.8
Restronguet Creek	*Scrobicularia plana*	bivalve	0.0551	34.0	617.5
Tamar Estuary	*Scrobicularia plana*	bivalve	0.0109	5.4	496.0

* Interstitial water As concentration ** converted to wet weight based on a water content of 84.1%

BAF Studies

Cooper and Gillespie. 2001. Environmental Pollution. 111:67-74

Scope: Study was designed to measure concentrations of As and Hg associated with different components (sediment, water, fish) of a NW Mississippi

Dry Weight Basis

Location	Species	Common Name	Total As Cw mg/L*	Total As Ct mg/kg**	Total As BAF
Moon Lake	freshwater fish species		0.00512	0.0	7.2
Moon Lake	benthivorous fish		0.00512	0.0	8.9
Moon Lake	omnivorous fish		0.00512	0.1	20.3
Moon Lake	planktivorous fish		0.00512	0.0	0.8
			* Average of six sites	** dry weight	

Wet Weight Basis

Location	Species	Common Name	Total As Cw mg/L*	Total As Ct mg/kg**	Total As BAF
Moon Lake	freshwater fish species		0.00512	0.0	1.8
Moon Lake	benthivorous fish		0.00512	0.0	2.2
Moon Lake	omnivorous fish		0.00512	0.0	5.1
Moon Lake	planktivorous fish		0.00512	0.0	0.2
			* Average of six sites	** converted to wet weight assuming 75% water content	

Giusti and Zhang. 2002. Environmental Geochemistry and Health 24:47-65.

Scope: Study of the trace metal distribution in sediments, marine water and mussel Mytilus galloprovincialis of the Venetian Lagoon, Island of Murano

Dry Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L	Total As Ct mg/kg*	Total As BAF
B	Mytilus galloprovincialis	Mussel	0.0039	18.0	4615.4
E	Mytilus galloprovincialis	Mussel	0.00473	16.1	3403.8
F	Mytilus galloprovincialis	Mussel	0.00323	12.3	3808.0
H	Mytilus galloprovincialis	Mussel	0.0019	12.0	6315.8
				*Edible portion, composite samples (n = 15 to 20 mussels per site)	

Wet Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L	Total As Ct mg/kg*	Total As BAF
B	Mytilus galloprovincialis	Mussel	0.0039	3.6	923.1
E	Mytilus galloprovincialis	Mussel	0.00473	3.2	680.8
F	Mytilus galloprovincialis	Mussel	0.00323	2.5	761.6
H	Mytilus galloprovincialis	Mussel	0.0019	2.4	1263.2

BAF Studies
* converted to wet weight assuming 80% water content

BAF Studies

Chen and Folt. 2000. Environmental Science & Technology, 34:3878-3884.

Scope: Bioaccumulation (and Diminution) of As in Freshwater Food Web

Dry Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L*	Total As Ct mg/kg**	Total As BAF
Upper Mystic Lake	zooplankton (small)	NA	0.000781	17.2	21959.0
Upper Mystic Lake	zooplankton (large)	NA	0.000781	10.7	13738.8
Upper Mystic Lake		alewife	0.000781	0.3	381.6
Upper Mystic Lake		killifish	0.000781	0.3	343.1
Upper Mystic Lake		black crappie	0.000781	0.1	158.8
Upper Mystic Lake		bluegill sunfish	0.000781	0.1	190.8
Upper Mystic Lake		yellow perch	0.000781	0.2	234.3
Upper Mystic Lake		largemouth bass	0.000781	0.1	184.4
			* average of 3 samples (June, August, October)	** dry weight	

Wet Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L*	Total As Ct mg/kg**	Total As BAF
Upper Mystic Lake	zooplankton (small)	NA	0.000781	3.4	ERR
Upper Mystic Lake	zooplankton (large)	NA	0.000781	2.1	2747.8
Upper Mystic Lake		alewife	0.000781	0.1	95.4
Upper Mystic Lake		killifish	0.000781	0.1	85.8
Upper Mystic Lake		black crappie	0.000781	0.0	39.7
Upper Mystic Lake		bluegill sunfish	0.000781	0.0	47.7
Upper Mystic Lake		yellow perch	0.000781	0.0	58.6
Upper Mystic Lake		largemouth bass	0.000781	0.0	46.1
			*average of 3 samples (June, August, October)	** converted to wet weight assuming 75% water content for fish and 80% for zooplankton	

BAF Studies

Chen et al. 2000. Limnology and Oceanography 45:1525-1536.

Scope: Arsenic in food web across a gradient of lakes

Dry Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L	Total As Ct mg/kg*	Total As BAF**
Canobie Lake	Small zooplankton		0.000221	10.4	95.4
Canobie Lake	Large zooplankton		0.000221	2.4	10905.0
Chaffin Pond	Large zooplankton		0.000113	0.1	964.6
Clear Pond	Small zooplankton		0.000046	0.1	2804.3
Clear Pond	Large zooplankton		0.000046	0.3	5869.6
Community Lake	Small zooplankton		0.000367	1.4	3842.0
Community Lake	Large zooplankton		0.000367	0.3	768.4
Gregg Lake	Small zooplankton		0.00038	5.9	15421.1
Gregg Lake	Large zooplankton		0.00038	1.6	4131.6
Horseshoe Pond	Small zooplankton		0.000078	7.6	97435.9
Horseshoe Pond	Large zooplankton		0.000078	0.5	6717.9
Ingham Pond	Small zooplankton		0.000587	1.1	1925.0
Ingham Pond	Large zooplankton		0.000587	2.1	3509.4
Island Pond	Small zooplankton		0.00026	6.5	25038.5
Lake Placid	Small zooplankton		0.000123	0.8	6422.8
Lake Placid	Large zooplankton		0.000123	0.4	2951.2
Lower Kohanza Reservoir	Small zooplankton		0.000085	0.3	3152.9
Lower Kohanza Reservoir	Large zooplankton		0.000085	0.2	1952.9
Mirror Lake	Small zooplankton		0.000409	1.0	2518.3
Mirror Lake	Large zooplankton		0.000409	0.6	1371.6
Palmer pond	Small zooplankton		0.000022	0.3	11909.1
Post pond	Small zooplankton		0.00026	0.5	1846.2
Post pond	Large zooplankton		0.00026	0.9	3642.3
Queen Lake	Small zooplankton		0.000107	0.9	8654.2
Queen Lake	Large zooplankton		0.000107	0.3	2869.2
Tewksbury pond	Small zooplankton		0.000057	2.2	39122.8
Tewksbury pond	Large zooplankton		0.000057	0.2	2894.7
Turkey pond	Small zooplankton		0.00026	9.9	38115.4
Turkey pond	Large zooplankton		0.00026	3.0	11500.0
Williams Lake	Small zooplankton		0.000096	1.4	14687.5
Williams Lake	Large zooplankton		0.000096	0.5	4812.5
All lakes	Piscivores and omnivores	freshwater fish	0.000174	0.6	3281.6

*dry weight

**BAF for fish was back calculated from the Log BAF and Cw

BAF Studies

Chen et al. 2000. Limnology and Oceanography 45:1525-1536.

Scope: Arsenic in food web across a gradient of lakes

Wet Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L	Total As Ct mg/kg*	Total As BAF**
Canobie Lake	Small zooplankton		0.000221	2.1	2894.7
Canobie Lake	Large zooplankton		0.000221	0.5	2181.0
Chaffin Pond	Large zooplankton		0.000113	0.0	192.9
Clear Pond	Small zooplankton		0.000046	0.0	560.9
Clear Pond	Large zooplankton		0.000046	0.1	1173.9
Community Lake	Small zooplankton		0.000367	0.3	768.4
Community Lake	Large zooplankton		0.000367	0.1	153.7
Gregg Lake	Small zooplankton		0.00038	1.2	3084.2
Gregg Lake	Large zooplankton		0.00038	0.3	826.3
Horseshoe Pond	Small zooplankton		0.000078	1.5	19487.2
Horseshoe Pond	Large zooplankton		0.000078	0.1	1343.6
Ingham Pond	Small zooplankton		0.000587	0.2	385.0
Ingham Pond	Large zooplankton		0.000587	0.4	701.9
Island Pond	Small zooplankton		0.00026	1.3	5007.7
Lake Placid	Small zooplankton		0.000123	0.2	1284.6
Lake Placid	Large zooplankton		0.000123	0.1	590.2
Lower Kohanza Reservoir	Small zooplankton		0.000085	0.1	630.6
Lower Kohanza Reservoir	Large zooplankton		0.000085	0.0	390.6
Mirror Lake	Small zooplankton		0.000409	0.2	503.7
Mirror Lake	Large zooplankton		0.000409	0.1	274.3
Palmer pond	Small zooplankton		0.000022	0.1	2381.8
Post pond	Small zooplankton		0.00026	0.1	369.2
Post pond	Large zooplankton		0.00026	0.2	728.5
Queen Lake	Small zooplankton		0.000107	0.2	1730.8
Queen Lake	Large zooplankton		0.000107	0.1	573.8
Tewksbury pond	Small zooplankton		0.000057	0.4	7824.6
Tewksbury pond	Large zooplankton		0.000057	0.0	578.9
Turkey pond	Small zooplankton		0.00026	2.0	7623.1
Turkey pond	Large zooplankton		0.00026	0.6	2300.0
Williams Lake	Small zooplankton		0.000096	0.3	2937.5
Williams Lake	Large zooplankton		0.000096	0.1	962.5
All lakes	Piscivores and omnivores	freshwater fish	0.000174	0.1	361.0

BAF Studies
* converted to wet weight based on 88% water content for fish (as in the article) and 80% for zooplankton

BAF Studies

Mason et al. 2002. Archives of Environmental Contamination and Toxicology 38:283-297.

Scope: Bioaccumulation of As and other metals by freshwater Inverts and fish

Wet Weight Basis

Species	Common Name	Location	Dissolved As Cw mg/L	Total As Ct mg/kg**	Total As BAF
	periphyton	Blacklick	0.00037	0.6	1600.3
	periphyton	Herrington Creek	0.00067	1.4	2062.1
	bryophytes	Blacklick	0.00037	1.1	2915.9
	bryophytes	Herrington Creek	0.00067	1.6	2415.5
Diptera/Tipulidae	cranefly	Blacklick	0.00037	0.9	2400.5
Diptera/Tipulidae	cranefly	Herrington Creek	0.00067	0.3	392.8
Tricoptera/Hydropsychidae	caddisfly	Blacklick	0.00037	1.0	2809.5
Tricoptera/Hydropsychidae	caddisfly	Herrington Creek	0.00067	1.2	1846.0
Ephemeroptera/Heptageniidae	mayfly	Blacklick	0.00037	2.1	5618.6
Ephemeroptera/Heptageniidae	mayfly	Herrington Creek	0.00067	1.7	2543.1
Plecoptera/Pteronacidae/Pteronarcys	shredder stonefly	Blacklick	0.00037	0.2	604.6
Plecoptera/Perlidae/Acroneuria	predatory stonefly	Blacklick	0.00037	0.5	1333.5
Plecoptera/Perlidae/Acroneuria	predatory stonefly	Herrington Creek	0.00067	0.6	824.8
Odonata/Aeshnidae/Aeshna	dragonfly	Blacklick	0.00037	0.1	195.7
Odonata/Aeshnidae/Aeshna	dragonfly	Herrington Creek	0.00067	0.8	1256.9
Megaloptera/Corydalidae	dobsonfly	Blacklick	0.00037	0.4	1102.4
Megaloptera/Corydalidae	dobsonfly	Herrington Creek	0.00067	0.3	432.1
Crustacea/Decapoda	Crayfish	Blacklick	0.00037	0.2	489.2
Crustacea/Decapoda	Crayfish	Herrington Creek	0.00067	0.4	646.4
Ameierus nebulosus	Brown Bullhead	Herrington Creek	0.00067	0.2	283.9
Catostomus commersoni	White Sucker	Herrington Creek	0.00067	0.3	376.1
Cottus bairdi	Mottled Sculpin	Blacklick	0.00037	0.3	798.1
Rhinichthys atratulus	Blacknose Dace	Blacklick	0.00037	0.2	512.7
Semotilus atromaculatus	Creek Chub	Harrington Creek	0.00067	0.2	281.5
Salvelinus fontinalis	Small Brook Trout	Blacklick	0.00037	0.2	571.1
Salvelinus fontinalis	Small Brook Trout	Harrington	0.00067	0.2	308.2
Salvelinus fontinalis	Large Brook Trout	Blacklick	0.00037	0.1	304.6
Salvelinus fontinalis	Large Brook Trout	Harrington Creek	0.00067	0.2	237.8

*whole body

BAF Studies

Wagemann et al. 1978. Archives of Environmental Contamination and Toxicology 7:169-191.

Scope: As in water and Biota from Lakes in N. West Canada

Dry Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L*	Total As Ct mg/kg**	Total As BAF
Grace Lake	Pelecypoda	*Herbivore*	0.027	23.2	859.3
Grace Lake	Gastropoda	*Herbivore*	0.027	14.8	548.1
Kam Lake	Gastropoda	*Herbivore*	2.58	133.0	51.6
Kam Lake	Oligochaeta	*Herbivore*	2.58	820.0	317.8
Grace Lake	Ephemeroptera	*Herbivore*	0.027	51.0	1888.9
Grace Lake	Trichoptera	*Herbivore*	0.027	14.3	529.6
Kam Lake	Trichoptera	*Herbivore*	2.58	56.0	21.7
Grace Lake	Chironomidae	*Herbivore*	0.027	31.0	1148.1
Kam Lake	Chironomidae	*Herbivore*	2.58	125.0	48.4
Grace Lake	zooplankton	*Herbivore*	0.027	26.7	988.9
Kam Lake	zooplankton	*Herbivore*	2.58	710.0	275.2
Grace Lake	Hemiptera: Notonectidae	*Carnivore*	0.027	3.2	118.1
Kam Lake	Hemiptera: Notonectidae	*Carnivore*	2.58	30.0	11.6
Grace Lake	Hemiptera: Gerridae	*Carnivore*	0.027	1.8	66.7
Grace Lake	Odonata: Anispotera	*Carnivore*	0.027	9.2	341.5
Kam Lake	Odonata: Anispotera	*Carnivore*	2.58	57.5	22.3
Grace Lake	Odonota: Zygoptera	*Carnivore*	0.027	5.5	204.4
Kam Lake	Odonota: Zygoptera	*Carnivore*	2.58	2.0	0.8
Grace Lake	Coleoptera: Dytiscidae	*Carnivore*	0.027	6.5	240.4
Kam Lake	Coleoptera: Dytiscidae	*Carnivore*	2.58	32.1	12.4
Grace Lake	Coleoptera: Gyrinidae	*Carnivore*	0.027	2.6	95.9
Kam Lake	Coleoptera: Gyrinidae	*Carnivore*	2.58	14.6	5.7
Grace Lake	Diptera: Ceratopogonidae	*Carnivore*	0.027	3.5	129.6
Kam Lake	Diptera: Ceratopogonidae	*Carnivore*	2.58	12.0	4.7
Kam Lake	Chironomidae: Tanypodinae	*Carnivore*	2.58	40.0	15.5
Kam Lake	Hydracarnia	*Carnivore*	2.58	51.6	20.0
Grace Lake	Hirudinea	*Carnivore*	0.027	2.7	100.7
Kam Lake	Hirudinea	*Carnivore*	2.58	190.0	73.6
Grace Lake	Cottus cognatus	*Carnivore*; sculpin	0.027	7.6	282.2
Kam Lake	Cottus cognatus	*Carnivore*; sculpin	2.58	122.0	47.3
Grace Lake	Amphipoda	*Omnivore*	0.027	14.5	537.0
Grace Lake	Hemiptera: Corixidae	*Omnivore*	0.027	3.8	141.5
Kam Lake	Hemiptera: Corixidae	*Omnivore*	2.58	44.1	17.1

BAF Studies

*Average of 1975 monthly samples **Geometric mean of whole body samples collfrin summer months 1975

Wagemann et al. 1978. Archives of Environmental Contamination and Toxicology 7:169-191.

Scope: As in water and Biota from Lakes in N. West Canada

Wet Weight Basis

Location	Species	Common Name	Dissolved As Cw mg/L	Total As Ct mg/kg**	Total As BAF
Grace Lake	Pelecypoda		0.027	4.6	171.9
Grace Lake	Gastropoda		0.027	3.0	109.6
Kam Lake	Gastropoda		2.58	26.6	10.3
Kam Lake	Oligochaeta		2.58	164.0	63.6
Grace Lake	Ephemeroptera		0.027	10.2	377.8
Grace Lake	Trichoptera		0.027	2.9	105.9
Kam Lake	Trichoptera		2.58	11.2	4.3
Grace Lake	Chironomidae		0.027	6.2	229.6
Kam Lake	Chironomidae		2.58	25.0	9.7
Grace Lake	zooplankton		0.027	5.3	197.8
Kam Lake	zooplankton		2.58	142.0	55.0
Grace Lake	Hemiptera: Notonectidae	*Carnivore*	0.027	0.6	23.6
Kam Lake	Hemiptera: Notonectidae	*Carnivore*	2.58	6.0	2.3
Grace Lake	Hemiptera: Gerridae	*Carnivore*	0.027	0.4	13.3
Grace Lake	Odonata: Anispotera	*Carnivore*	0.027	1.8	68.3
Kam Lake	Odonata: Anispotera	*Carnivore*	2.58	11.5	4.5
Grace Lake	Odonota: Zygoptera	*Carnivore*	0.027	1.1	40.9
Kam Lake	Odonota: Zygoptera	*Carnivore*	2.58	0.4	0.2
Grace Lake	Coleoptera: Dytiscidae	*Carnivore*	0.027	1.3	48.1
Kam Lake	Coleoptera: Dytiscidae	*Carnivore*	2.58	6.4	2.5
Grace Lake	Coleoptera: Gyrinidae	*Carnivore*	0.027	0.5	19.2
Kam Lake	Coleoptera: Gyrinidae	*Carnivore*	2.58	2.9	1.1
Grace Lake	Diptera: Ceratopogonidae	*Carnivore*	0.027	0.7	25.9
Kam Lake	Diptera: Ceratopogonidae	*Carnivore*	2.58	2.4	0.9
Kam Lake	Chironomidae: Tanypodinae	*Carnivore*	2.58	8.0	3.1
Kam Lake	Hydracarnia	*Carnivore*	2.58	10.3	4.0
Grace Lake	Hirudinea	*Carnivore*	0.027	0.5	20.1
Kam Lake	Hirudinea	*Carnivore*	2.58	38.0	14.7
Grace Lake	Cottus cognatus	*Carnivore*; sculpin	0.027	1.9	70.6
Kam Lake	Cottus cognatus	*Carnivore*; sculpin	2.58	30.5	11.8
Grace Lake	Amphipoda	*Omnivore*	0.027	2.9	107.4
Grace Lake	Hemiptera: Corixidae	*Omnivore*	0.027	0.8	28.3

BAF Studies					
Kam Lake	Hemiptera: Corixidae	*Omnivore*	2.58	8.8	3.4
				* converted to wet weight assuming 80% water content for invertebrates and 75% for fish	

BAF Studies

Lin et al. 2001. Bulletin of Environmental Conamination and Toxicology 67:91-97.

Scope: Bioaccumulation of As in Mullet in Fish Ponds using As contaminated groundwater

Dry Weight Basis

Location	Species	Common Name	Total As Cw mg/L	Total As Ct mg/kg*	Total As BAF
Putai 3	*Liza macrolepis*	Mullet	0.1697	2.2	13.2
				* value is average As in dorsal muscle of eleven fish	

Wet Weight Basis

Location	Species	Common Name	Total As Cw mg/L	Total As Ct mg/kg*	Total As BAF
Putai 3	*Liza macrolepis*	mullet	0.1697	0.6	3.3
				* Converted to wet weight assuming 75% water content	

Baker and King. 1994. Environmental contamination investigations of water quality, sediment, and biota of the upper Gila River Basin,

Scope: As in water and biota of the San Francisco River (site 2) and Upper Gila River, AZ.

Wet Weight Basis

Locaton	Species	Common Name	Total As Cw mg/L**	Total As Ct mg/kg	Total As BAF
2	*Ictalurus punctatus*	Channel Catfish	0.02	0.1	5.0
2	*Pilodictis olivaris*	FH Catfish*	0.02	0.1	5.0
4	*Ictalurus punctatus*	Channel Catfish	0.034	0.1	2.9
4	*Pilodictis olivaris*	FH Catfish	0.034	0.1	2.9
5	*Ictalurus punctatus*	Channel Catfish	0.017	0.1	5.9
5	*Pilodictis olivaris*	FH Catfish	0.017	0.1	5.9
6	*Cyprinis carpio*	Carp	0.025	0.1	4.0
7	*Pilodictis olivaris*	FH Catfish	0.01	0.1	10.0
7	*Cyprinis carpio*	Carp	0.01	0.1	10.0
7	*Pilodictis olivaris*	FH Catfish*	0.01	0.1	10.0
8	*Cyprinis carpio*	Carp	0.011	0.1	9.1
9	*Ictalurus punctatus*	Channel Catfish	0.008	0.2	25.0
9	*Cyprinis carpio*	Carp	0.008	0.1	12.5
9	*Micropterus salmoides*	LM Bass	0.008	0.3	37.5
9	*Ictalurus punctatus*	Channel Catfish*	0.008	0.1	12.5
9	*Micropterus salmoides*	LM Bass*	0.008	0.1	12.5
10	*Cyprinis carpio*	Carp	0.008	0.2	25.0

BAF Studies		
	*Edible portion	** water sample is average of 3 monthly samples collected June thru August 1990 when fish were collected

APPENDIX E

ARSENIC TOTAL: DISSOLVED CHEMICAL TRANSLATOR

Dissolved Fraction (f-d) of Arsenic (As) for Lentic Systems				
Author/Location	**As-D (nM)**	**As-T (nM)**	**As f-d**	**As log (f-d)**
Anderson and Bruland (1991)/CA Davis Creek Reservoir				
10/23/88- depth, m= 0	24.9	25.8	0.965	-0.015
10/23/88- depth, m= 3.7	26.8	25.6	1.000	0.000
10/23/88- depth, m= 15.2	22.4	32.4	0.691	-0.161
10/23/88- depth, m= 17.7	19.6	37.9	0.517	-0.287
			0.766	-0.116
12/20/88- depth, m= 0	23.9	22.6	1.000	0.000
12/20/88- depth, m= 3.7	24.2	23.2	1.000	0.000
12/20/88- depth, m= 7.6	23.8	23.3	1.000	0.000
12/20/88- depth, m= 12.2	24.8	23.1	1.000	0.000
12/20/88- depth, m= 16.8	24.2	21.9	1.000	0.000
			1.000	0.000
2/13/89-depth, m=0	17.8	15.9	1.000	0.000
2/13/89-depth, m=3.7	17.4	16.4	1.000	0.000
2/13/89-depth, m=7.6	16.4	16.5	1.000	0.000
2/13/89-depth, m=12.2	16.8	16.3	1.000	0.000
2/13/89-depth, m=16.8	15.6	16.4	0.950	-0.022
			0.987	-0.006
	GM for the three dates:		0.918	
Chen and Folt (2000)/Upper Mystic Lake, MA				
Summer, 1997	0.85	0.985	0.86	-0.066
Fall, 1997	0.65	0.72	0.9	-0.046
			0.88	-0.056

Dissolved Fraction (f-d) of Arsenic (As) for Lotic Systems				
Author/Location	**As-D (ug/L)**	**As-T (ug/L)**	**As f-d**	**As log (f-d)**
Tanzaki et al (1992)/Japan				
Tamagawa River- S-1	0.596	0.655	0.910	-0.041
Tamagawa River- S-2	0.530	0.578	0.917	-0.038
Tamagawa River- S-3	0.785	0.851	0.924	-0.034
Tamagawa River- S-4	0.719	0.754	0.954	-0.020
Tamagawa River- S-5	0.409	0.898	0.455	-0.342
Tamagawa River- S-6	0.535	0.535	1	0.000
Sagamigawa River- S-7	0.325	0.382	0.851	-0.070
Sagamigawa River- S-8	0.356	0.380	0.937	-0.028
'Tamagawa and Sagamigawa Rivers			0.862	-0.076
Waslenchuk (1979)/GA				
Ogeechee River	0.265	0.36	0.736	-0.133
Hering and Kneebone (2002)/CA				
Los Angelos Aqueduct, channel	4.6	5.7	0.807	-0.093
Michel et al./France				
Seine River*	1.65	1.76	0.938	-0.028

*Average of samples from the 210-280 Kmn to Paris zone of freshwater.

Dissolved Fraction (f-d) of Arsenic (As) for Estuarine Systems					
Author/Location	**As-D (ug/L)**	**Particulate As (ug/L)**	**As-T (ug/L)**	**As f-d**	**As log (f-d)**
Milward et al. (1997)/England					
Thames estuary					
Febuary, 1989	3.277	0.227	3.504	0.935	-0.029
July, 1990	2.292	0.133	2.425	0.945	-0.024
				0.940	-0.027

Dissolved Fraction (f-d) of Arsenic (As) for Combined Surface Drinking Water Sources						
Author/Location	**Relative Sample Contribution**	**Range of As f-d**	**Mid-Range of As f-d**	**Weighted Dissolved Sample Contribution***	**Log Relative Contribution**	**Log Weighted Contribution**
Chen et al. (1999)/ U.S. Surface Drinking Water Sources						
	6.54	0.901-1	0.950	6.210	0.816	0.793
	5.05	0.789-0.901	0.845	4.270	0.703	0.630
	6.35	0.783-0.789	0.783	4.970	0.803	0.696
	5.85	0.756-0.783	0.770	4.500	0.767	0.653
	5.61	0.753-0.756	0.754	4.230	0.749	0.626
	5.79	0.72-0.753	0.737	4.270	0.763	0.630
	5.79	0.693-0.72	0.706	4.090	0.763	0.612
	5.99	0.673-0.693	0.683	4.090	0.777	0.612
	6.16	0.651-0.673	0.662	4.080	0.790	0.611
	5.61	0.589-0.651	0.610	3.420	0.749	0.534
	6.36	0.589-0.589	0.589	3.750	0.803	0.574
	4.48	0.5-0.589	0.544	2.440	0.651	0.387
	6.54	0.497-0.56	0.498	3.260	0.816	0.513
	5.43	0.483-0.497	0.490	2.660	0.735	0.425
	5.79	0.451-0.483	0.467	2.700	0.763	0.431
	6.17	0.441-0.451	0.446	2.750	0.790	0.439
	4.67	0.182-0.441	0.312	1.460	0.669	0.164
	5.70			3.418	0.756	0.534
	GM f-d:	5.74xf-d=3.54				
	f-d=	0.60				

*relative sample contribution x midrange f-d.

APPENDIX F

TISSUE ARSENIC SPECIATION DATA

APPENDIX F: TISSUE SPECIATION DATA

Study Type	Trophic Level	Article #	Tissue	Common Name	Total As Ct mg/kg	Inorganic As Ct mg/kg	Inorganic As Fraction	As (III) Ct mg/kg	As (III) Fraction	As (V) Ct mg/kg	As (V) Fraction	Organic As Fraction	MMA Ct mg/kg	MMA Fraction	DMA Ct mg/kg	DMA Fraction	TMA Ct mg/kg	TMA Fraction	AsB Ct mg/kg	AsB Fraction	AsC Ct mg/kg	AsC Fraction
Freshwater -Field	**2**	40	whole body	marsh snail	0.186							1.058			0.05	0.269	0.116	0.624				
	2	40	whole body	caddisfly larva	0.236							1.173			0.202	0.856	0.022	0.093				
	2	40	whole body	caddisfly pupa	2.05							3.004			1.18	0.576	0.839	0.409				
				GMEAN	**0.4481**										**0.2284**		**0.1289**					
Freshwater-Lab	**2**	1	whole body	waterflea	18			13	0.722	4.6	0.256		0.060		0.3	0.017						
(Water Exposure)	**2**	1	whole body	waterflea	19.4			14.6	0.753	4.6	0.237		0.020		0.18	0.009						
	2	1	whole body	waterflea	35.2			22	0.625	12.8	0.364		0.020		0.42	0.012						
				GMEAN	**23.0784**			**16.1030**	**0.6978**	**6.4701**	**0.2804**		**0.0288**		**0.2831**	**0.0123**						
	2	1	whole body	shrimp	1			0.46	0.460	0.2	0.220				0.32	0.320						
	2	1	whole body	shrimp	1.88			0.9	0.479	0.6	0.340				0.34	0.181						
	2	1	whole body	shrimp	2.2			0.82	0.373	1.2	0.555				0.16	0.073						
				GMEAN	**1.6052**			**0.6976**	**0.4346**	**0.5559**	**0.3463**				**0.2592**	**0.1615**						
	2	31	whole body	zooplanktonic grazer	0.94	0.42	0.447								0.52	0.553						
	2	32, 33	whole body	shrimp	3.78	3.18	0.841					0.759			0.38	0.101	0.22	0.058				
	2	32, 33	whole body	shrimp	3.7	2.98	0.805					0.915			0.38	0.103	0.34	0.092				
	2	32, 33	whole body	shrimp	3.96	3.46	0.874					0.626			0.28	0.071	0.22	0.056				
	2	32, 33	whole body	shrimp	4.52	3.08	0.681					1.759			0.52	0.115	0.92	0.204				
	2	32, 33	whole body	shrimp	6.64	6.04	0.910					0.690			0.34	0.051	0.26	0.039				
	2	32, 33	whole body	shrimp	6.32	5.58	0.883					0.857			0.44	0.070	0.3	0.047				
				GMEAN	**4.6799**	**3.8784**	**0.8287**					**0.8761**			**0.3828**	**0.0818**	**0.3251**	**0.0695**				

APPENDIX F: TISSUE SPECIATION DATA

Study Type	Trophic Level	Article #	Tissue	Common Name	Total As Ct mg/kg	Inorganic As Ct mg/kg	Inorganic As Fraction	As (III) Ct mg/kg	As (III) Fraction	As (V) Ct mg/kg	As (V) Fraction	Organic As Fraction	MMA Ct mg/kg	MMA Fraction	DMA Ct mg/kg	DMA Fraction	TMA Ct mg/kg	TMA Fraction	AsB Ct mg/kg	AsB Fraction	AsC Ct mg/kg	AsC Fraction
Freshwater-Lab	**2**	1,3	whole body	waterflea	41.8			18.4	0.440	23.4	0.560											
(Dietary Exposure - lab foodchain model)	**2**																					
	2	1	whole body	shrimp	2.5			0.44	0.176	2.0	0.808				0.04	0.016						
	2	1	whole body	shrimp	6.4			0.6	0.094	5.8	0.906											
	2	4	whole body	shrimp	6.4			0.6	0.094	5.8	0.906											
				GMEAN	**4.6784**			**0.5411**	**0.1157**	**4.0807**	**0.8722**				**0.0400**	**0.0160**						
		31	whole body	zooplanktonic grazer	15.12	13.24	0.876								1.88	0.124						
		31	whole body	zooplanktonic grazer	22.2	16.66	0.750					3.930	1.860	0.084	3.68	0.166						
		33	whole body	shrimp	5.12	4.52	0.883								0.286	0.056						

APPENDIX F: TISSUE SPECIATION DATA

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Freshwater-Field	**3**	40	whole body	prawn	0.817										0.614	0.752	0.187					
	3	40	whole body	dobsonfly larva	2.875										2.762	0.961	0.043					
	3	26	whole body	freshwater crayfish	0.6	0.44	0.733												0.054	0.090		
	3	26	whole body	freshwater crayfish	1.26														0.056	0.044		
	3	26	whole body	freshwater crayfish	0.32	0.15	0.469												0.0112	0.035		
	3	26	whole body	freshwater crayfish	0.62	0.42	0.677												0.024	0.039		
	3	26	whole body	freshwater crayfish	0.76	0.44	0.579												0.034	0.045		
	3	26	whole body	freshwater crayfish	1														0.034	0.034		
	3	26	whole body	freshwater crayfish	0.4	0.174	0.435												0.05	0.125		
	3	26	whole body	freshwater crayfish	1.16	0.72	0.621												0.022	0.019		
	3	26	whole body	freshwater crayfish	1.26														0.024	0.019		
	3	26	whole body	freshwater crayfish	1.02	0.56	0.549												0.03	0.029		
	3	26	whole body	freshwater crayfish	1.7	1.08	0.635												0.028	0.016		
	3	26	whole body	freshwater crayfish	0.52	0.36	0.692												0.0118	0.023		
	3	26	whole body	freshwater crayfish	0.52	0.48	0.923												0.054	0.104		
				GMEAN	**0.7660**	**0.4172**	**0.6179**												**0.0296**	**0.0386**		
	3	26	whole body	freshwater crayfish	0.26														0.016	0.062		
	3	26	whole body	freshwater crayfish	0.24														0.038	0.158		
	3	26	whole body	freshwater crayfish	0.36	0.22	0.611												0.0144	0.040		
	3	26	whole body	freshwater crayfish	0.32	0.068	0.213												0.026	0.081		
				GMEAN	**0.2912**	**0.1223**	**0.3604**												**0.0218**	**0.0750**		
	3	40	whole body	amphidromous goby	0.37							1.326			0.089	0.241	0.269	0.727				
	3	40	whole body	Japanese dace	0.1							1.056			0.076	0.760	0.02	0.200				
	3	40	whole body	downstream fatminnow	0.267							1.224			0.061	0.228	0.197	0.738				
	3	40	whole body	goby	0.333							1.261			0.077	0.231	0.238	0.715				
	3	40	whole body	sweet fish	0.051							0.927			0.005	0.098	0.04	0.784				
	3	26	whole body	freshwater crayfish	0.5	0.146	0.292												0.022	0.044		
	3	26	whole body	freshwater crayfish	1.44	0.86	0.597															

APPENDIX F: TISSUE SPECIATION DATA

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	3	26	whole body	freshwater crayfish	0.44														0.0134	0.030		
	3	26	whole body	freshwater crayfish	0.82																	
	3	26	whole body	freshwater crayfish	0.76														0.017	0.022		
				GMEAN	**0.7229**	**0.3543**	**0.4176**												**0.0171**	**0.0311**		
Freshwater-Lab	3	1	whole body	tilapia	0.675			0.15	0.222	0.0	0.074	1.179					0.475	0.704				
(Water Expsoure)	3	1	whole body	tilapia	0.8			0.15	0.187	0.1	0.094	1.294					0.575	0.719				
	3	1	whole body	tilapia	5.15			2.025	0.393	1.8	0.359	1.248	0.275	0.053	0.4	0.078	0.6	0.117				
				GMEAN	**1.4063**			**0.3572**	**0.2540**	**0.1907**	**0.1356**	**1.2391**	**0.2750**	**0.0534**	**0.4000**	**0.0777**	**0.5472**	**0.3891**				
	3	3	whole body	Japanese medaka	5.3			1.375	0.259	1.6	0.292	1.598	1.225	0.231	0.6	0.113	0.55	0.104				
	3	3	whole body	Japanese medaka	53.25			38.25	0.718	11.5	0.216	1.066	2.500	0.047			1	0.019				
	3	3	whole body	Japanese medaka	80.25			41.5	0.517	36.2	0.452	0.781	1.750	0.022	0.75	0.009						
	3	3	whole body	Japanese medaka	77.75			34.25	0.441	41.5	0.534	0.026	2.000	0.026								
	3	3	whole body	Japanese medaka	62.5			27	0.432	32.5	0.520	1.048	2.000	0.032	0.875	0.014	0.125	0.002				
				GMEAN	**40.5811**			**18.2390**	**0.4494**	**15.4189**	**0.3800**	**0.5140**	**1.8460**	**0.0455**	**0.7329**	**0.0246**	**0.4097**	**0.0157**				
	3	4	whole body	tilapia	0.85			0.25	0.294	0.2	0.294	0.762					0.35	0.412				
	3	4	whole body	tilapia	1.9			0.725	0.382	0.7	0.382	0.612	0.075	0.039	0.125	0.066	0.25	0.132				
	3	4	whole body	tilapia	2.8			1.125	0.402	1.2	0.429	0.570	0.075	0.027	0.175	0.062	0.225	0.080				
				GMEAN	**1.6536**			**0.5886**	**0.3559**	**0.6014**	**0.3637**	**0.6427**	**0.0750**	**0.0325**	**0.1479**	**0.0641**	**0.2700**	**0.1633**				
	3	4	whole body	tilapia	5.15			2.025	0.393	1.8	0.359	1.248	0.275	0.053	0.4	0.078	0.6	0.117				
	3	4	whole body	tilapia	3			0.975	0.325	0.9	0.300	1.350	0.150	0.050	0.275	0.092	0.7	0.233				
	3	4	whole body	tilapia	3.075			1.25	0.407	1.2	0.374	0.870	0.025	0.008	0.25	0.081	0.4	0.130				
				GMEAN	**3.6218**			**1.3514**	**0.3731**	**1.2418**	**0.3429**	**1.1356**	**0.1010**	**0.0279**	**0.3018**	**0.0833**	**0.5518**	**0.1524**				
	3	4	whole body	tilapia	0.625			0.25	0.400	0.2	0.280	0.370	0.150	0.240			0.05	0.080				
	3	4	whole body	tilapia	2.475			1.025	0.414	1.0	0.384	0.377	0.325	0.131			0.175	0.071				
	3	4	whole body	tilapia	3.025			1.2	0.397	0.9	0.289	0.614	0.650	0.215			0.3	0.099				
				GMEAN	**1.6726**			**0.6750**	**0.4035**	**0.5259**	**0.3144**	**0.4408**	**0.3164**	**0.1892**			**0.1379**	**0.0825**				
	3	4	whole body	tilapia	0.475							1.475			0.15	0.316	0.325	0.684				
	3	4	whole body	tilapia	1.775							2.775			0.625	0.352	1.15	0.648				
	3	4	whole body	tilapia	5.25			0.95	0.181			5.119			1.8	0.343	2.5	0.476				

APPENDIX F: TISSUE SPECIATION DATA

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				GMEAN	**1.6419**			**0.9500**	**0.1810**			**2.7569**			**0.5526**	**0.3366**	**0.9776**	**0.5954**				
	3	31	whole body	guppy	1.7	1.25	0.735					0.565	0.150	0.088	0.025	0.015	0.275	0.162				
	3	31	whole body	guppy	1.725	1.45	0.841					0.409	0.025	0.014	0.05	0.029	0.2	0.116				
	3	31	whole body	guppy	10	7.65	0.765					1.110	1.480	0.148	0.175	0.017	0.7	0.070				
				GMEAN	**3.0838**		**0.7791**	**#NUM!**		**#NUM!**		**0.6356**	**0.1771**	**0.0574**	**0.0603**	**0.0195**	**0.3377**	**0.1095**				
	3	32	muscle	carp	0.95	0.9	0.947					0.103					0.05	0.053				
	3	32	muscle	carp	1.5	1.25	0.833					0.317	0.100	0.067	0.05	0.033	0.1	0.067				
	3	32	muscle	carp	1.45	1.15	0.793					0.457	0.050	0.034	0.025	0.017	0.225	0.155				
	3	32	muscle	carp	1.8	1.5	0.833					0.342	0.125	0.069	0.075	0.042	0.1	0.056				
	3	32	muscle	carp	2.85	1.75	0.614					0.711	0.775	0.272	0.15	0.053	0.175	0.061				
	3	32	muscle	carp	3	1.775	0.592					1.008	0.625	0.208	0.25	0.083	0.35	0.117				
				GMEAN	**1.7799**	**1.3491**	**0.7579**					**0.3922**	**0.1978**	**0.0980**	**0.0811**	**0.0402**	**0.1379**	**0.0775**				
Freshwater-Lab	**3**	1	whole body	Tilapia	6.65			2.75	0.414	3.8	0.564	0.173					0.15	0.023				
(Dietary Exposure - lab foodchain model)	**3**	4	whole body	Tilapia	6.75			2.75	0.407	3	0.444						0.25	0.037				
	3	1	whole body	freshwater minnow	0.55			0.35	0.636	0.2	0.364											
	3	1	whole body	freshwater minnow	0.4			0.25	0.625	0.2	0.375											
	3	3	whole body	Japanese Medaka	12.5			3.25	0.260	9.2	0.740											
												0.287										
	3	31	whole body	guppy	0.925	0.125	0.135					1.665					0.8	0.865				
	3	31	whole body	guppy	1.4	0.225	0.161					2.014			0.025	0.018	1.15	0.821				
Freshwater-Field	**4**	40	whole body	masu salmon	0.146							1.130			0.063	0.432	0.081	0.555				

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Saltwater-Field	**2**	8	edible	blue mussel	1.022														0.888	0.869		
	2	27	edible	clam	1.9	0.025	0.025															
	2	27	edible	clam	2.3	0.015	0.007															
	2	27	edible	clam	2.9	0.018	0.006															
	2	27	edible	clam	4.2	0.018	0.004															
	2	27	edible	clam	3.2	0.017	0.005															
	2	27	edible	clam	8.4	0.009	0.001															
	2	27	edible	clam	4.2	0.021	0.005															
	2	27	edible	clam	2.2	0.015	0.007															
	2	27	edible	clam	12	0.008	0.001															
	2	27	edible	clam	2.8	0.022	0.008															
	2	27	edible	clam	2.1	0.02	0.010															
	2	27	edible	clam	3.4	0.035	0.010															
	2	27	edible	clam	2.3	0.022	0.010															
	2	27	edible	clam	3	0.021	0.007															
				GMEAN	**3.3442**	**0.0178**	**0.0053**															
	2	27	edible	cockle clam	1.1	0.02	0.018															
	2	27	edible	littleneck clam	6.9	0.02	0.003															
	2	27	edible	littleneck clam	2.2	0.02	0.009															
	2	27	edible	littleneck clams	2.4	0.02	0.008															
	2	8	soft	marine snail	6.106														5.984	0.980		
	2	8	soft	marine snail	5.408														5.138	0.950		
	2	27	edible	oyster	2.1	0.01	0.005															
	2	25	edible	oysters	10										0.68	0.068			10.4	1.040		
	2	20	whole body	marine polychaetes						0.010									0.64			
	2	20	whole body	marine polychaetes						0.013									0.70			
	2	20	whole body	marine polychaetes						0.024									0.78			
	2	20	whole body	marine polychaetes						0.022									0.60			
	2	20	whole body	marine polychaetes						0.119									0.53			
	2	20	whole body	marine polychaetes						0.149									0.70			
	2	20	whole body	marine polychaetes															0.81		0.0127	
	2	20	whole body	marine polychaetes															1.22		0.0095	
	2	20	whole body	marine polychaetes															0.77		0.0206	
	2	20	whole body	marine polychaetes						0.051									0.66		0.0175	
	2	20	whole body	marine polychaetes						0.208									0.83		0.0222	

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	2	20	whole body	marine polychaetes						0.211									0.58		0.0190	

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Saltwater-Field	**3**	27	edible	sand dab	4.5	0.01	0.002															
	3	27	edible	rock sole	17	0.05	0.003															
	3	27	edible	red rock crab	3.6	0.03	0.008															
	3	2	edible	gastropod	46.6														44.7	0.959		