



J.R. Simplot Company
Simplot Headquarters
1099 W. Front Street
Boise, Idaho 83702
P.O. Box 27
Boise, Idaho 83707

July 24, 2023

SUBMITTED VIA EMAIL TO: elizabeth.spelsberg@deq.idaho.gov

Ms. Beth Spelsberg
Idaho Department of Environmental Quality
Water Quality Division
1410 North Hilton Street
Boise, ID 83706

Dear Ms. Spelsberg:

The Department of Environmental Quality (Department) is seeking comments on the June 2023 *Draft Implementation Guidance for Idaho's Human Health Water Quality Criteria for Arsenic* (docket no. 58-0102-2201) (Draft Guidance). The J.R. Simplot Company (Simplot) was extensively involved in the negotiated rulemaking for setting the new human health water quality criteria (HHWQC) for arsenic. This participation included attending the rulemaking meetings, providing comments and working with the Idaho Association of Commerce and Industry on comments throughout this rulemaking. Furthermore, Simplot has a number of business interests throughout the State of Idaho that are subject to the arsenic human health water quality criteria. Thus, these criteria will have direct impact on water discharges or remedial actions that involve Simplot operations. Simplot has several comments for consideration by the Department on the Draft Guidance.

A mark-up of the Draft Guidance with recommended edits (shown in redline-strikeout) is attached. The more substantive of the those, along with reasoning for the suggested change, are also presented below. Also attached is the final version of the paper titled "*Inorganic arsenic concentration in fish governed by trophic level and size, not water concentration: implications for human health water quality criteria*" that Simplot referred to in its May 2023 comment letter. That paper has now been published in a recent issue of *Environmental Toxicology and Chemistry*.

Specific comments.

Page vi, Executive Summary. When discussing the fate of arsenic in the environment the second paragraph of the Executive Summary states “...it cannot be neutralized or destroyed.” Simplot agrees that arsenic cannot be destroyed. However, “neutralized” implies a changing of form to reduce an effect such as when reducing acidity or alkalinity of a solution. Arsenic can change forms, such as from inorganic to organic as is in the case of metabolism by fish. The end of the above sentence in the attached mark-up of the Draft Guidance was changed to “...it cannot be destroyed, but it can change forms. For example, from inorganic to organic.” This same change was also made in the first paragraph of Section 2.2.1 on page 12 of the attached mark-up of the Draft Guidance

Page vii, Executive Summary. When discussing the translation of the 8 ug/kg fish tissue criterion to a water column criterion, the sentence states “...may result in a water column value more or less stringent than the statewide water column element depending on the site-specific conditions.” Because the translated water column criterion, whatever that ends up being, is based on the 8 ug/kg fish tissue criterion, the “stringency” of the criterion has not changed. All water column concentrations are based on the allowed 8 ug/kg of inorganic arsenic in fish tissue. As shown in the attached mark-up of the Draft Guidance, the end of the above sentence was changed to “...may result in a water column value greater than or less than the statewide water column element depending on the site-specific conditions.”

Page 15, first paragraph. The recent publication referred to above (*Inorganic arsenic concentration in fish governed by trophic level and size, not water concentration: implications for human health water quality criteria*) presents evidence of the diminution of arsenic in higher trophic level fish in Idaho. Simplot recommends adding that citation to the others already listed in the at the end of this paragraph.

Page 18, last paragraph. A citation to “Table 3” was added to the last sentence of this paragraph as Simplot was unable to find reference to that table elsewhere in the attached mark-up of the Draft Guidance.

Page 21, First paragraph. Averaging of all gamefish tissue. Simplot continues to recommend that when more than one composite sample of gamefish is available, the compliance determination be based on the average of all gamefish samples and not the single gamefish sample with the highest concentration. Use of the average of all samples, assuming more than one sample is available, rather than the single highest sample is consistent with other aspects of the proposed fish tissue criterion. For example, the criterion is derived using a fish consumption rate that represents consumption of all species of gamefish, not a single species. The average of all gamefish samples better represents the concentration in all gamefish species than the single highest gamefish species sample. Additionally, the proposed rule specifies that gamefish species samples are to be composite samples of a minimum of five individual fish. A composite sample represents the average concentration of the individual fish used to create the sample. The proposed rule’s use of a composite recognizes that variation exists between individual fish and that an average of several individuals better represents the concentration in receiving water fish than does the concentration in a single fish. Similarly, the average of several composite samples of different gamefish species, assuming such are available, better

represents the concentration in receiving water fish than does the concentration of a single gamefish species sample. For these reasons, Simplot continues to recommend use of an average of all receiving water gamefish species composite samples, when more than a single composite gamefish species sample is available.

Page 23, first bullet in Section 4.3.1. Fish biologist consultation. The bullet refers to “a fish biologist consultation” when conducting a water column translation. Simplot requests clarification and confirmation that as part of the water column translation application process such consultation needs to be with a fish biologist with appropriate experience and background. The consultation does not need to be with a Department fish biologist, though Simplot understands that a fisheries biologist from the Department may be involved in the Department’s review of a proposed site-specific water column translation.

Page 29, Fishless Waters, second to last bullet. Bioaccumulation dynamics in downstream waters. The second to last bullet lists seasonal variability of inorganic arsenic (iAs) concentrations in the water column and fish tissue as a consideration when developing a site-specific trophic level weighted-bioaccumulation factor (TL-BAF). As long as the water column and fish tissue samples are collected at the same time, the iAs concentration in fish should reflect the effect of the concentration of iAs in the water column. The TL-BAF derived from those paired samples is assumed to be applicable to different iAs concentrations that may occur at other times of the year. While it is certainly possible that the water column and fish tissue concentrations could change seasonally, the relationship between the two (i.e., the TL-BAF) is assumed to remain relatively constant and can be combined with the relevant water column concentration for the iAs criterion (i.e., the arithmetic mean) to predict the average fish tissue concentration. This is true even if the TL-BAF was developed using paired data collected at a time of year when the water column concentration was substantially higher or lower than the arithmetic mean annual concentration. Simplot recommends that “seasonal” variability be deleted from the second bullet (see attached mark-up of the Draft Guidance).

Page 35, 11.2 Establishing Permit Conditions, second bullet. This bullet indicates that if iAs in fish tissue exceeds the tissue criterion of 8 µg/kg, then it will be determined that there is Reasonable Potential To Exceed (RPTE) the human health inorganic arsenic criteria and arsenic effluent limits will be required. Before a tissue exceedance downstream of a discharge can be deemed positive evidence of RPTE, it needs to be shown that the iAs concentration in the downstream tissue samples exceeds the iAs concentration in upstream tissue samples. If the iAs concentration in both up and downstream samples is similar but exceeds the fish tissue criterion element of 8 µg/kg, that is an indication of naturally occurring iAs concentrations above the fish tissue element and not an indication of RPTE. Given that iAs occurs naturally in Idaho waters and fish tissues, the discussion of RPTE in the implementation guidance needs to include language that allows permittees to determine if fish tissue criterion element exceedances represent RPTE or natural conditions.

Page 39, References. Morrison et al, citation. The title in the citation was updated and the journal issue and page number added.

Appendix B, section 1) b) ii). Simplot appreciates the expanded list of potential application scenarios for the proposed iAs criterion and believes this will help discharge permit

applicants understand their monitoring options. The Draft Guidance in this section of the outline indicates that if the water column criterion is not met, the water body is not in compliance with the recreational use element. Note that for this set of scenarios “1) *Recreational use waters **with fish***” (emphasis added) fish tissue could be collected and analyzed, but for the scenarios listed in “b) *Water column data available, fish tissue data not available*”, such fish tissue collection and analysis has not yet happened. Therefore, scenarios in which the water column element is not met have the potential to collect fish to determine if the fish tissue element is met or not. Those have been added to the outline of scenario in the mark-up of the Draft Guidance and the explanation of the “b)” scenario clarified.

Appendix B, section 2) a) iv) (2). In situations where a water body is not in compliance with the DWS element but fish tissue data are available and indicate the water body is in compliance with the recreational use element, the Draft Guidance calls for demonstrating continued compliance by developing a site-specific fish tissue to water column translation. Simplot recommends that continuing compliance can also be demonstrated by collecting fish tissue. The bullet was expanded in the mark-up of the Draft Guidance to state “**And** continued collection of fish tissue data can be used to demonstrate continued compliance with recreational criterion element, or a water column translation value can be developed using a site-specific BAF and continuing compliance with the recreational use element demonstrated using water column data.”

We appreciate the opportunity to provide these comments and recommended edits to the Department.

Sincerely,

A handwritten signature in blue ink, appearing to read 'Alan L. Prouty', is positioned above the printed name and title.

Alan L. Prouty
Vice President, Environmental & Regulatory Affairs

Attachments (2)

Draft Implementation Guidance for Idaho's Human Health Water Quality Criteria for Arsenic

Water Quality: Docket No. 58-0102-2201



**State of Idaho
Department of Environmental Quality**



June 2023

www.deq.idaho.gov

Prepared by

Beth Spelsberg, India Southern, and Chantilly Higbee
Idaho Department of Environmental Quality
Water Quality Division
1410 N. Hilton St.
Boise, ID 83706

Accessibility Services: The Idaho Department of Environmental Quality will provide reasonable language access services and/or disability services for documents at no charge. To request an accommodation under Title VI of the Civil Rights Act of 1964 or Americans with Disabilities Act, contact DEQ's nondiscrimination coordinator at (208) 373-0271 or accessibility@deq.idaho.gov. Para obtener información en español, visite <https://www.deq.idaho.gov/about-us/accessibility/>.

DEQ, June 2023, PID 9155, CA code 82136. Costs associated with this publication are available from the State of Idaho Department of Environmental Quality in accordance with Idaho Code § 60-202.

Table of Contents

Abbreviations, Acronyms, and Symbols	v
Executive Summary.....	vi
1 Introduction.....	8
1.1 Purpose.....	8
1.2 Human Health Water Quality Criteria for Arsenic.....	9
2 Background.....	11
2.1 Sources of Arsenic in the Environment	11
2.2 Species of Arsenic.....	12
2.2.1 Effects of Physical and Chemical Properties on Speciation of Arsenic.....	12
2.3 Arsenic in Surface Water	12
2.3.1 Background Arsenic Levels in Idaho	13
2.4 Effects of Arsenic on Human Health.....	14
2.5 Bioaccumulation and Biotransformation of Arsenic in Fish Species	15
2.5.1 Uptake of Inorganic Arsenic	16
3 Bioaccumulation Factor.....	17
3.1 Trophic-Level Weighted BAF	18
4 Criteria Overview.....	19
4.1 Recreational Use Criteria.....	19
4.1.1 Fish Tissue Element.....	20
4.1.2 Water Column Element	21
4.2 Domestic Water Supply Criterion.....	21
4.3 Water Column Translation	22
4.3.1 Water Column Translation Data Requirements	23
4.3.2 Calculating a Site-Specific Water Column Translation	24
4.3.3 Example Water Column Translation Calculation	25
5 General Implementation Considerations	26
5.1 Fish-Tissue Monitoring and Assessment.....	26
5.1.1 Recommended Species.....	27
5.1.2 Sampling Assessment	27
5.1.3 Spatial Considerations	27
5.1.4 Temporal Considerations.....	28
6 Fishless Waters	28
7 Identifying Impairments for Integrated Report.....	29
8 Antidegradation	30
9 Clean Water Act § 401 Water Quality Certifications.....	30

10	TMDL Process.....	31
10.1	Subbasin Assessment	32
10.2	Loading Analysis	32
11	Idaho Pollutant Discharge Elimination System.....	33
11.1	Reasonable Potential to Exceed	34
11.2	Establishing Permit Conditions.....	34
	References	36
	Appendix A. Formulas Used to Develop the Arsenic Rule	41
	Appendix B. Example Scenarios for Applying Human Health Criteria for Arsenic.	43
	Appendix C. Water Column Translation Criterion Decision Tree	46

List of Tables

Table A. Dual-element human health criteria for arsenic.	vi
Table 1. Criteria for protecting human health (Table 2, IDAPA 58.01.02.210.01.b).	9
Table 2. TL assignments for calculating Idaho-specific TL-BAF and geometric mean of calculated bioaccumulation factors by TL.	18
Table 3. TL-specific consumption rates from the national fish consumption study.	19
Table 4. TL assignments for calculating TL-BAF.	25

List of Figures

Figure 1. Map of Idaho arsenic monitoring study sites.	14
Figure 2. Uptake, biotransformation, and elimination pathways of arsenic (Zhang et al. 2022).	16

List of Equations

Equation 1. TL-BAF calculation.	19
Equation 2. Result for statewide TL-BAF calculations.	19
Equation 3. Translation BAF calculation.	24
Equation 4. Translation TL-BAF calculation.	24
Equation 5. Water column translation calculation.	25

Abbreviations, Acronyms, and Symbols

µg	microgram
AU	assessment unit
BAF	bioaccumulation factor
BCF	bioconcentration factor
CWA	Clean Water Act
DEQ	Idaho Department of Environmental Quality
DMA	dimethylarsinate
DWS	domestic water supply
EPA	United States Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GPS	Global Positioning System
IDFG	Idaho Department of Fish and Game
IPDES	Idaho Pollutant Discharge Elimination System
kg	kilogram
L	liter
MCL	maximum contaminant level
mg	milligram
MMA	monomethylarsonate
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RPTE	reasonable potential to exceed
SDWA	Safe Drinking Water Act
TL-BAF	trophic level weighted bioaccumulation factor
TMDL	total maximum daily load
WBAG	Water Body Assessment Guidance
WDE	Washington Department of Ecology
WLA	waste load allocation
WQBEL	water quality-based effluent limits

Executive Summary

This document is intended to assist the Idaho Department of Environmental Quality (DEQ) in maintaining and implementing a consistent statewide approach for implementing the Idaho human health water quality criteria for arsenic. This document does not create a right or benefit, substantive or procedural, enforceable at law or equity by any party against DEQ, its employees, or any other person. This document does not substitute existing requirements of the Clean Water Act (CWA), federal regulations, or Idaho's "Water Quality Standards" (IDAPA 58.01.02). The recommendations in this guidance are not binding; DEQ may consider other approaches consistent with the CWA, federal regulations, and Idaho's water quality standards. DEQ may change or update this guidance in the future.

Arsenic is a naturally occurring element, released into the environment through natural processes such as geothermal, erosion, forest fires, or through human activities such as mining. Arsenic is classified into three main groups: (1) inorganic (typically the most toxic form), (2) organic, and (3) arsine gas. Once arsenic is released into the environment, it cannot be ~~neutralized or destroyed~~, but it can change forms. For example, from inorganic to organic. The extent of arsenic adsorption to suspended solids and sediments in the water column or stream bed strongly depends upon the temperature, humic content, sediment type, pH of the water, and species of arsenic. In surface waters, arsenic is transported in the water column but also will bind to particles in the water or sediment on the bottom of lakes or rivers.

Unlike other metals such as mercury and selenium, arsenic is not highly bioaccumulative. Due to the lack of evidence for a strong relationship between fish tissue and water column levels of arsenic, DEQ believes that the rule and implementation principles in the rule, including the use of a trophic level weighted bioaccumulation factor (TL-BAF) and a dual tissue/water column criterion, will account for changing or increasing arsenic conditions.

The fish only exposure for recreational beneficial use is a dual-element criterion consisting of a fish tissue element and a water column element, with the fish tissue element superseding the water column element. The water and fish exposure for domestic water supply (DWS) beneficial use is a water column element only. However, the more sensitive use will apply, so the recreational beneficial use criterion would apply in most scenarios.

Table A. Dual-element human health criteria for arsenic.

Metal	Water and Fish	Fish Only
Arsenic (inorganic)	10 µg/L water column	4.3 µg/L water column 8.0 µg/kg fish tissue

Notes: microgram per liter (µg/L); microgram per kilogram (µg/kg)

Fish tissue concentration is compared to the criterion based on an average or composite of a *minimum* of five individual fish of the same species, collected from the same water body within the same calendar year, defined as January 1–December 31. When available, game fish species representative of the size and species that may be *legally harvested* within the water body

should be used. If game fish are not available, other species may be used. The fish tissue criterion can only be used if no new activity or discharge occurs that contributes arsenic to the water body within the prior 90 days.

In developing effluent limits for waters designated for recreation, the fish tissue element may be translated to a water column value using a site-specific TL-BAF based on the ratio of total recoverable inorganic arsenic in fish tissue to dissolved inorganic arsenic in the water column. The site-specific translation is not a site-specific criterion, it is a translation of the fish tissue element to an applicable water column target using both the fish tissue criterion and a site-specific TL-BAF. The translation directly incorporates the fish only fish tissue criterion for recreational waters of 8.0 µg/kg but may result in a water column value greater than more or less stringent than the statewide water column element depending on the site-specific conditions. If the translated criterion exceeds the water and fish criterion (10 µg/L) in waters also designated for DWS, then the water and fish criterion would apply instead of the translated fish only criterion, as the more stringent use criterion applies.

Using this guidance, DEQ will implement the criterion across programs, including but not limited to, collecting samples and interpreting results and assessing fishless waters and fish tissue sample size and monitoring requirements. For Idaho Pollutant Discharge Elimination System permits, DEQ acknowledges the challenges a fish tissue criterion presents in the context of water quality-based permitting and recommends engaging early with the agency when developing a sampling and analysis plan before any sampling or monitoring activities occur.

1 Introduction

States must develop criteria that protect designated beneficial uses and are based on sound science (Clean Water Act [CWA] § 303(c)(2)(A); 40 CFR 131.11(a)). Additionally, states are required to adopt criteria for toxic pollutants for which the United States Environmental Protection Agency (EPA) has published recommended criteria under CWA § 304(a) and where the discharge or presence of those pollutants in the affected waters could reasonably be expected to interfere with designated uses adopted by the state (CWA § 303(c)(2)(B)). States have the discretion to adopt the EPA's criteria recommendations, EPA's recommendations modified to reflect site-specific conditions, or criteria based on other scientifically defensible methods (CWA 40 § 131.11(b)(1)(ii)). DEQ developed the human health water quality criteria for arsenic according to CWA § 303(c) and the federal regulations implementing the CWA, 40 CFR 131, et seq.

In May 2016, EPA entered into a consent decree with Northwest Environmental Advocates to reconsider EPA's 2010 approval of Idaho's human health criteria for arsenic. In September 2016, EPA disapproved Idaho's human health criteria of 10 micrograms per liter (µg/L) arsenic for both consumption of fish only and consumption of water and fish. The consent decree required that EPA propose new human health criteria for arsenic by November 15, 2018, and that EPA either approve Idaho's submittal of revised human health criteria for arsenic or promulgate federal criteria by July 15, 2019. In June 2018 and again in June 2022, the court granted the Unopposed Motion to Modify Consent Decree, ultimately extending the November 15, 2018, and July 15, 2019, deadlines to November 15, 2023, and November 15, 2024, respectively.

In 2018, the Idaho Department of Environmental Quality (DEQ) initiated negotiated rulemaking, which is a public process with stakeholder engagement. This rulemaking enabled Idaho to begin the process to adopt human health criteria for arsenic under state-negotiated rulemaking, and if approved, would prevent federal promulgation of criteria for Idaho by EPA. During the negotiated rulemaking process, eight meetings were held between April 2018 and November 2020. On December 9, 2020, a preliminary draft rule was posted on DEQ's website. Five additional meetings were held between December 2020 and November 2021, for a total of 13 negotiated rulemaking meetings. Stakeholders and members of the public participated by attending the meetings, reviewing DEQ's presentations and supporting information, and submitting comments. Key information was posted on DEQ's website and distributed to persons who participated in the negotiated rulemaking. All comments received during the negotiated rulemaking process were considered by DEQ when making decisions about the rule's development. In May 2022, the rule was presented to the DEQ Board and approved. It was then reviewed and approved by the Idaho Legislature during the 2023 session.

1.1 Purpose

This document provides guidance to DEQ staff, the regulated community, and the general public for implementing the statewide human health water quality criteria for arsenic and

applies only to surface waters in Idaho. The criteria reflect the latest Idaho-specific arsenic surface water and fish tissue monitoring data. The criteria were developed by using a TL-BAF, which is the preferred method in EPA's *Methodology for Deriving Water Quality Criteria for the Protection of Human Health* (EPA 2000).

The final criteria are expressed both in terms of concentrations of total recoverable inorganic arsenic in fish tissue (fillet or muscle) and dissolved inorganic arsenic in the water column. DEQ developed this guidance, based upon Idaho's "Water Quality Standards" (IDAPA 58.01.02) and the resulting criteria developed from the negotiated rulemaking.

The implementation principles outlined in this guidance ensure that all of Idaho surface waters will be adequately protected for recreational uses, and any waters designated for domestic water supply (DWS) will be adequately protected as source water for public drinking water systems.

1.2 Human Health Water Quality Criteria for Arsenic

Human health criteria are set to protect humans from exposures from both recreational uses, such as swimming, boating, or fishing, and DWS use that is intended to protect public drinking water supply source waters (Table 1). Although all Idaho waters are expected to meet recreational uses, (IDAPA 58.01.02.100.02), only certain water bodies identified in IDAPA 58.01.02.110-160 are designated for DWS. Frequency and duration for human health toxics criteria must not be exceeded based on an annual arithmetic mean concentration (IDAPA 58.01.02.210.03.d.ii).

The criteria in IDAPA 58.01.02.210 ~~is~~ are provided below. Section 4 discusses each part of the criteria in detail.

Table 1. Criteria for protecting human health (Table 2, IDAPA 58.01.02.210.01.b).

Criteria for Protection of Human Health (based on the consumption of:)						
Compound	CAS Number	Carcinogen?	Water & Fish (µg/L unless otherwise specified)		Fish Only (µg/L unless otherwise specified)	
Inorganic Compounds/Metals						
Arsenic	7440382	Y	10	c, d, j	4.3; 8.0 µg/kg fish issue	c, k

Footnotes:

c. Inorganic forms only.

d. Criterion expressed as total recoverable (unfiltered) concentrations.

j. This criterion is based on the drinking water Maximum Contaminant Level (MCL).

k. For Fish Only exposure to inorganic arsenic, the human health criterion is:

Fish Tissue (µg/kg wet-weight)

8.0

Water Column (µg/L)

4.3

Fish tissue element is based on total recoverable inorganic arsenic in muscle or fillet. The fish tissue element supersedes the water column element provided at

least ninety (90) days have passed since any new activity or discharge has occurred within the water body. Fish tissue element will be applied in accordance with Subsection 210.03.e.

Water column element is based on dissolved inorganic arsenic in water.

Subsection 210.03.e.

e. Application of the fish tissue element of the arsenic criterion for human health.

i. The fish tissue element for total recoverable inorganic arsenic is based on a single measurement using sufficiently sensitive methods.

ii. The single measurement must be made on a sample that is an average or composite of a minimum of five (5) individual fish of the same species, collected from the same water body within the same calendar year. When available, game fish species representative of the size and species that may be legally harvested within the water body are preferred. Results from multiple sample events may be averaged or composited provided they represent the same species collected from the same water body within the same calendar year.

iii. Not to be exceeded; the Department will evaluate all representative fish tissue data to determine compliance with this criterion element.

iv. For purposes of determining water column targets for the development of effluent limits, TMDL targets, or water column targets for fishless waters, the fish tissue element may be translated to a water column value using a site-specific bioaccumulation factor (BAF) based on the ratio of total recoverable inorganic arsenic in fish muscle or fillet tissue to dissolved inorganic arsenic in the water column using the following equation:

$$WC_T(\mu g / L) = \frac{8.00 \mu g / kg}{BAF_{ss} L / kg}$$

Water Column Translation Calculation.

Where:

WC_T ($\mu g/L$) is the translated water column value; and

BAF_{ss} L/kg is the site specific BAF calculated consistent with 210.03.e.v.

In fishless waters, surface water and fish tissue from the immediate downstream waters may be used for bioaccumulation modeling. In the absence of sufficient fish tissue data, the water column element is the applicable criterion element in fishless waters.

v. When translating the fish tissue element to a water column value, the following procedures will be followed.

(1) Data used to translate the fish tissue element must be based on current conditions and consistent with Subsections 210.03.e.i. and ii.

(2) Whenever practical, fish tissue samples must be representative of the game fish species present within the water body and include game fish of legally harvestable size. In the absence of suitable game fish species, other resident fish species may be used.

(3) Water column samples must be representative of the annual average concentration of dissolved inorganic arsenic at the site.

(4) BAFs are calculated as a trophic-level weighted BAF or other scientifically defensible method for deriving protective BAF.

2 Background

2.1 Sources of Arsenic in the Environment

Arsenic is a naturally occurring element found in the earth's crust. Arsenic is released into the environment through natural processes such as volcanic activity (including geothermal, as occurs in a number of Idaho waters), erosion, forest fires, or through human activities such as pesticide application, improper disposal of arsenic-containing waste chemicals, agricultural applications, mining, and smelting (CLU-IN 2022; Chung et al. 2014; ATSDR 2007a).

Anthropogenic sources of arsenic releases to water include mining, smelting, wastewater, [dumping-disposal](#) of sewage sludge, coal burning power plants, manufacturing processes, urban runoff, atmospheric deposition, and waste from poultry farms (ATSDR 2007a; Gorny et al. 2015).

Arsenic in surface water typically originates from mining activities and the natural weathering of soil and rocks. Arsenic is present in more than 200 minerals, primarily as arsenate and arsenic sulfides and occasionally as arsenites, oxides, and elemental arsenic (Faria et al. 2023). Arsenic is generally found at higher concentrations in igneous and sedimentary rocks, such as sandstones, shales, and phosphorites, than in other rock types and is also commonly associated with sulfide deposits. Clays, sedimentary iron, and manganese oxides can also be rich in arsenic (Ghosh et al. 2022; CLU-IN 2022; NRC 1977). Arsenopyrite is the most common sulfide mineral and is generally associated with gold mining (Faria et al. 2023). A large part of arsenic from mining originates from leaching of abandoned mine tailing and fly ash waste piles. Significant amounts of arsenic are also contained in liquid effluents from gold cyanidation milling processes (ATSDR 2007a).

2.2 Species of Arsenic

Arsenic forms can be classified into three main groups: (1) inorganic (typically the most toxic form), (2) organic, and (3) arsine gas. The most common valence states of arsenic are As(0) (metalloid arsenic), As(III) (arsenite), As(V) (arsenate), and As(-3) (arsine gas) (ATSDR 2009). Arsenite and arsenate are the inorganic forms of arsenic. Arsenite is 60 times more toxic than arsenate because of its propensity to react with lipids, proteins, and other cellular components causing higher cellular uptake (Ventura-Lima et al. 2011; Khosravi-Darani et al. 2022). Arsenite is also highly soluble and mobile in aquatic systems (Khosravi-Darani, et al. 2022; Brusseau and Artiola 2019).

Due to the high toxicity of inorganic arsenic, and its prevalence as the common oxidation state in both ground and surface waters, both EPA and Idaho developed human health criteria for inorganic arsenic rather than total arsenic.

2.2.1 Effects of Physical and Chemical Properties on Speciation of Arsenic

Once arsenic is released into the environment, it cannot be ~~neutralized or destroyed~~ but it can change forms. For example, from inorganic to organic. It can only change its form or attach to or separate from particulates (Chung et al. 2014; ATSDR 2007b). Arsenic can be transformed by various reactions in the environment, including oxidation-reduction reactions, ligand exchange, precipitation, and biotransformation. These reactions are influenced by the oxidation-reduction potential, dissolved oxygen, pH, metal sulfide and sulfide ion concentrations, iron concentrations, temperature, salinity, and the distribution and composition of biota. (ATSDR 2007a; Zhang et al. 2022; Gorny et al. 2015; Shah et al. 2008). The combination of these environmental factors and rates of transformation determines the ratio of arsenic species in the environment.

The extent of arsenic adsorption to suspended solids and sediments in the water column or stream bed depends strongly upon the temperature, humic content, sediment type, and pH of the water and the arsenic species. In acidic and neutral waters, arsenate is more readily adsorbed, while arsenite is weakly adsorbed. Arsenite is present predominantly as arsenous acid (H_3AsO_3) at environmental pH (between 6.5 to 9) and is not strongly adsorbed to suspended solids and sediments in the water column (Gorny et al. 2015; EPA 2022a). Arsenate is predominantly present as dihydrogen arsenate (H_2AsO_4) and hydrogen arsenate (HAsO_4^{2-}) in most waters, which is considerably more adsorptive than arsenous acid. Sediment-bound arsenic may be released back into the water by chemical or biological interconversions of arsenic species, especially in high pH waters ($\text{pH} > 9$) (ATSDR 2007a; Gorny et al. 2015).

2.3 Arsenic in Surface Water

In aquatic systems, inorganic arsenic occurs primarily as arsenate and arsenite (Brusseau and Artiola 2019). In oxygenated waters (such as rivers), arsenate is the predominate form, while in reducing conditions (e.g., groundwaters), arsenite predominates (ATSDR 2007a; Rahman et al. 2012; WHO 2019). Products of methylation, monomethylarsonate (MMA), and

dimethylarsinate (DMA) can also [be](#) present and are the main organic forms of arsenic in freshwater (ATSDR 2007a).

In surface waters, arsenic is transported in the water column but also will bind to particles in the water or sediment on the bottom of lakes or rivers. Ultimately, most arsenic is adsorbed from water onto sediments or soils—especially clays, iron oxides, aluminum hydroxides, manganese compounds, and organic material (Gorny et al. 2015; ATSDR 2007a). Arsenic can also move from water and sediment into biofilm (attached algae, bacterial, and associated fine detritus), and then into invertebrates and fish (ATSDR 2007a). Under these conditions, arsenate and arsenic can undergo biomethylation to less harmful arsenic compounds. The uptake of arsenic from the water column into fish tissue is further discussed in section 2.5.

2.3.1 Background Arsenic Levels in Idaho

Elevated arsenic levels in Idaho groundwaters are well documented and are naturally occurring (CLU-IN 2022; DEQ 2023). From 2019 to 2021, DEQ conducted a probabilistic monitoring study to measure total and inorganic arsenic levels in paired surface water column and fish tissue samples and inorganic and total arsenic levels in surface waters throughout Idaho to derive an Idaho-specific inorganic arsenic human health criteria (Figure 1). Results of the monitoring study showed an average concentration of 1.63 µg/L of inorganic arsenic present in water column samples. Of the inorganic arsenic found, an average of 0.20 µg/L was arsenite with results as high as 1.87 µg/L, and 1.44 µg/L was arsenate with results as high as 20.80 µg/L.

An analysis of water quality portal data for inorganic arsenic in surface waters across Idaho from 2012 to 2022 showed average concentrations of 6.42 µg/L of total arsenic, and an average of 1.36 µg/L of inorganic arsenic in Idaho waters. Inorganic arsenic concentrations ranged from 0.47 µg/L to 2.07 µg/L (National Water Quality Monitoring Council 2022).

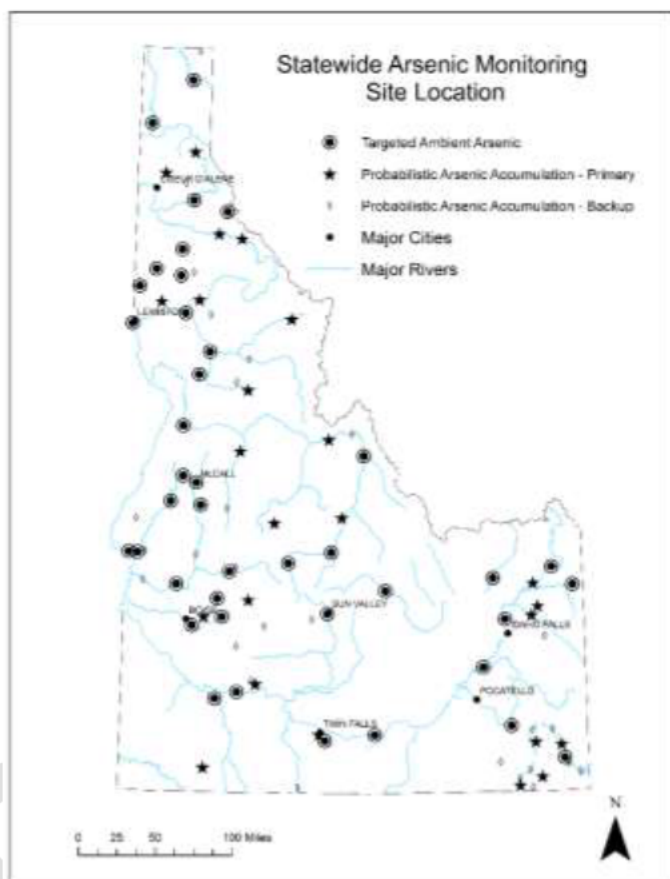


Figure 1. Map of Idaho arsenic monitoring study sites.

2.4 Effects of Arsenic on Human Health

The EPA classified inorganic arsenic as a Group A human carcinogen (EPA 2021a; IRIS 2017; NTP 2021). Acute oral exposure to inorganic arsenic can affect the digestive tract, respiratory system, central nervous system, cardiovascular system, and liver, and cause hematological effects and peripheral neuropathy. Acute exposure may also result in death. Chronic oral exposure to elevated levels of inorganic arsenic can result in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, as well as liver and kidney damage (EPA 2021a; IRIS 2017).

Chronic exposure to arsenic at a dose lower than 0.04 milligrams per kilograms per day (mg/kg/day) can increase occurrences of cancer (e.g., skin, bladder, lung, kidney, and liver) and have noncancerous effects on various physiological systems such as the cardiovascular, pulmonary immunological, neurological, and endocrine systems (ATSDR 2007a; IDWR 2002).

2.5 Bioaccumulation and Biotransformation of Arsenic in Fish Species

Aquatic organisms accumulate, retain, and transform arsenic species internally when exposed through diet and other sources such as water and sediments (Williams et al. 2006; Zhang et al. 2022; EPA 2003, 2000; Rahman et al. 2012). Bioaccumulation is the net accumulation of a chemical by an aquatic organism as a result of uptake from all environmental sources, including water, food, and sediment, and is measured as the final result of competing rates of chemical uptake and elimination (EPA 2003, 2000; Arnot and Gobas 2006). Rates of arsenic uptake and bioaccumulation depend on a variety of factors, such as aquatic setting (marine, estuarine, freshwater), organism type (fish, invertebrate), species, age, trophic status within the aquatic food chain, exposure concentrations, history of exposure, route of uptake, environmental pH, dissolved organic matter, and phosphorus content (Williams et al. 2006; Shah et al. 2008; Ghosh et al. 2022; Zhang et al. 2022). Arsenic does not appear to biomagnify through aquatic food chains; inorganic arsenic seems to diminish at high trophic levels due to the ability of organisms to biotransform and eliminate this form of arsenic (ATSDR 2007a; Williams et al. 2006; EPA 2003; Ghosh et al. 2022; [Morrison et al. 2023](#)).

Fish can ~~intake~~ ~~take up~~ arsenic ~~by uptake~~ from the water column across diffusion barriers into the blood and internal organs (e.g., through the gills and skin) or through assimilating contaminated food sources (Zhang et al. 2022; Ghosh et al. 2022; Rahman et al. 2012). Benthic species, such as algae and invertebrates, and benthic feeding fish often accumulate the most arsenic due to the exposure through arsenic accumulated in sediments (Cui et al. 2020; Ghosh et al. 2022; Rahman et al. 2012). Predatory fish may bioaccumulate metals from the surrounding water and from feeding on other fish, particularly benthic feeding species (Ghosh et al. 2022; ATSDR 2007a).

Once inside the organism, inorganic arsenic may metabolize into organic forms (Ghosh et al. 2022; Shah et al. 2008). Transformation pathways of inorganic arsenic are complex and are influenced by various environmental and organismal factors. However, a simple model of biotransformation of inorganic arsenic involves two types of chemical reactions: (1) the reduction of pentavalent arsenic (arsenate) to trivalent arsenic (arsenite) by glutathione (GSH) and (2) the oxidative methylation of trivalent to methylated pentavalent metabolites (MMA and DMA) with further transformation to arsenocholine (AsC) and arsenobetaine (AsB) (Chen et al. 2018; Cui et al. 2021; ATSDR 2007a). Arsenic species can accumulate in tissues or be eliminated from the body through excretion, molting, or passage to reproductive cells (Figure 2).

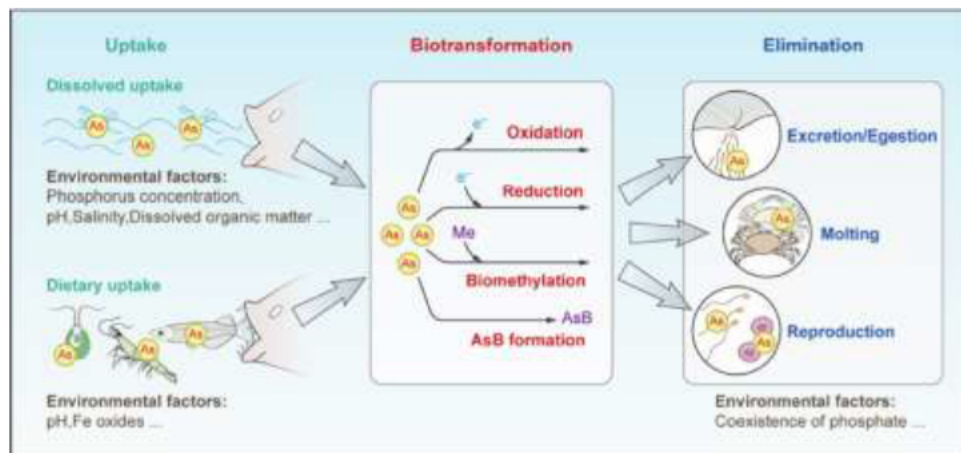


Figure 2. Uptake, biotransformation, and elimination pathways of arsenic (Zhang et al. 2022).

2.5.1 Uptake of Inorganic Arsenic

In 2019, DEQ conducted a probabilistic monitoring study to investigate the relationship of total and inorganic arsenic levels in paired water column and fish tissue samples to develop an Idaho-specific bioaccumulation [value factor](#) for human health criteria. The study found that fish tissue and water column levels of arsenic were weakly related, and the relationship was not statistically significant (p -value = 0.56) (DEQ 2020; Morrison et al 2023).

Due to the lack of evidence for a strong relationship between fish tissue and water column levels of arsenic, DEQ believes the rule and its implementation principles, including the use of TL-BAF and a dual tissue/water column criterion, will account for changing or increasing arsenic conditions. Unlike other metals, such as mercury and selenium, arsenic is not highly bioaccumulative. In fact, lower trophic level species are more likely to have elevated levels of inorganic arsenic than those at higher trophic levels (Morrison et al. 2023; Ghosh et al. 2022; ATSDR 2007a; Williams et al. 2006; EPA 2003). Little concern exists that small, incremental changes in water chemistry would result in drastic changes in fish tissue.

During negotiated rulemaking, stakeholders and DEQ considered whether new inputs or activities within a watershed would reach equilibrium quickly or would take a long time to manifest. The group decided to use a set buffer period after new or increased discharges. Research has shown varying lengths of time to achieve site equilibrium based on various environmental parameters and organism traits (EPRI 2008, 2011). Laboratory studies have shown that equilibrium for arsenic is close to 60 days in Rainbow Trout and Catfish, with arsenic levels beginning to decrease by 50% between days 60 and 90 (EPRI 2011, 2008). However, field conditions have many variables that can affect the rates of assimilation and elimination. DEQ has determined that a 90-day period after new activity or discharge should be sufficient to evaluate effective inorganic arsenic levels in fish tissue for protecting human health.

In IDAPA 58.01.02.010.65, ~~the definition for a~~ new activity or discharge is defined as follows:

...an activity or discharge that has not been previously authorized. Existing activities or discharges not currently permitted or licensed will be presumed to be new unless the Director determines to the contrary based on review of available evidence. An activity or discharge that has previously taken place without need for a license or permit is not a new activity or discharge when first licensed or permitted.

3 Bioaccumulation Factor

Bioaccumulation “is a process in which a chemical substance is absorbed in an organism by all routes of exposure as occurs in the natural environment, i.e., dietary and ambient environmental sources” (Arnot and Gobas 2006; EPA, 2000). A bioaccumulation factor represents the relationship of the concentration of a pollutant in the tissue of fish to the concentration in water and is often expressed as a ratio.

The lack of a strong relationship between water column and fish tissue levels of arsenic demonstrates the complexity in uptake routes and metabolism of arsenic, and a significant portion of arsenic found in fish could also be sourced through diet, not solely through absorption via the water column. Idaho’s water quality standards specify that DEQ will use a TL-BAF or bioconcentration factor (BCF) to derive human health criteria (IDAPA

58.01.02.210.05.b.ii). BCFs only consider the uptake of chemicals by exposure through the water column, while BAFs include both dietary contributions and direct uptake from the environment (e.g., diffusion across the gill surface) (Mackay et al. 2013; Arnot and Gobas 2006; EPA 2003, 2000). Both EPA and DEQ prefer field-based BAFs derived by collecting paired tissue and water column data over other estimates of bioaccumulation (e.g., BCFs) when determining human health criteria (EPA 2003).

National average BAFs for a given chemical and TL may not provide the most accurate estimate of bioaccumulation for certain water bodies in the United States. At a given location, the BAF for a chemical may be higher or lower than the national BAF, depending on the nature and extent of site-specific influences. In addition, the fish consumption habits of the local human population will guide the selection of the target species for which the investigator develops site-specific BAFs (EPA 2000). The bioaccumulation potential of a chemical can be affected by various site-specific physical, biological, and chemical factors.

Bioaccumulation factors for the Idaho human health criteria for arsenic were calculated from the Idaho probabilistic paired water column and fish tissue study (DEQ 2019). For each fish tissue sample (composite of five individuals), a corresponding water column sample was taken from the same location. BAFs were then calculated for each fish species and paired water column sample. BAFs are more representative of contaminant uptake by organisms from a variety of sources but do not capture the bioaccumulation potential of different species of fish. One way to reduce the variability between species BAFs, is to calculate each BAF by TL. More specifically, calculation by TL helps to account for broad physiological differences, such as lipid content or life stage, among organisms that may influence bioaccumulation (EPA 2003).

3.1 Trophic-Level Weighted BAF

A TL-BAF can be calculated by assigning fish to trophic level by species and using the BAFs at each TL and as a relative consumption proportion for each TL. To calculate a TL-BAF for arsenic human health criteria in Idaho, BAFs were calculated from the Idaho arsenic accumulation in fish tissue study (DEQ 2020).

For each species DEQ sampled, TL assignments were made based on a synthesis of information found in Simpson and Wallace (1982), Wallace and Zaroban (2013), Sigler and Zaroban (2018), and FishBase (Froese and Pauly 2000). A geometric mean was calculated from individual sample BAFs by TL (Table 2). TL2 fish are those fish that mostly consume TL1 organisms (primary producers such as algae and aquatic plants). TL3 fish are those fish that primarily consume TL2 organisms (aquatic invertebrates and TL2 fish). TL4 fish are predatory fish that primarily consume TL3 organisms (large aquatic invertebrates, other fishes).

Table 2. TL assignments for calculating Idaho-specific TL-BAF and geometric mean of calculated bioaccumulation factors by TL.

Trophic Level	Species	Rationale	Bioaccumulation Factor (L/kg)
2	Bridgelip Sucker	Herbivorous	2.99
3	Brook Trout, Channel Catfish, Common Carp, Cutthroat Trout, Longnose Dace, Mottled Sculpin, Mountain Whitefish, Rainbow Trout, Redside Shiner	Primarily invertivores, or opportunistic invertivore/piscivore where invertebrates make up a large component of diet	1.82
4	Brown Trout, Largemouth Bass, Northern Pike, Minnow, Smallmouth Bass	Primarily piscivores, or diet composed mostly of large invertebrates and fishes	0.27

Although Idaho fish consumption surveys did not specify consumption rates by species or by TL, it is possible to calculate a TL-BAF by using the proportions of TL-specific consumption rates from the national fish consumption rate [survey](#) and applying those proportions to Idaho's fish consumption rate. TL-specific consumption rates were based on the proportion of the 90th percentile of TL-specific consumption of freshwater and estuarine fishes to the total consumption rate from the national estimated fish consumption study and assigned to each TL ([Table 3](#); EPA 2014; DEQ 2021).

Table 3. TL-specific consumption rates from the national fish consumption study.

Trophic Level	National Consumption Rate (grams/day)	Proportion
2	7.6	0.36
3	8.6	0.40
4	5.1	0.24
Total	21.3	1.0

Source: EPA 2014. *Estimated Fish Consumption Rates for the U.S. Population and Selected Subpopulations*.

Using [Equation 1](#), a TL-BAF can be calculated using BAFs from the Idaho sampling data and TL-specific proportions from the national fish consumption rate.

$$TL\ BAF = [(BAF_{TL2})(P_{TL2}) + (BAF_{TL3})(P_{TL3}) + (BAF_{TL4})(P_{TL4})]$$

Equation 1. TL-BAF calculation.

Where:

TL-BAF= trophic level weighted BAF.

BAF_{TLi} = geometric mean of BAFs calculated for all samples for species assigned to TL_i .

P_{TLi} = proportion of national fish consumption rate for TL_i fishes.

This calculation results in a TL-BAF of 1.87 L/kg, representing the TL- BAF (

[Equation 2](#)):

$$TL\ BAF = [(2.99\ L/kg)(0.36) + (1.82\ L/kg)(0.40) + (0.27\ L/kg)(0.24)] = 1.87\ L/kg$$

Equation 2. Result for statewide TL-BAF calculations.

4 Criteria Overview

The following section contains an overview of the recreational (fish only) and DWS criteria. The fish only criterion has two elements, fish tissue and water column; while the DWS use criterion is a single criterion based on the Safe Water Drinking Act (SWDA) maximum contaminant level (MCL).

4.1 Recreational Use Criteria

The fish only exposure for recreational beneficial use is a dual-element criterion consisting of a fish tissue element and a water column element, with the fish tissue element superseding the water column element. Due to the uncertainty associated with bioaccumulation of inorganic arsenic, this two-part criterion provides a direct measure of the exposure route that is intended to be protected by allowing direct comparison of the fish tissue. In addition, it provides a water

column criterion that can be used when sufficient fish tissue data (section 4.1.1) might not be available or obtainable.

For this guidance, *water body* is defined as an assessment unit (AU) (IDAPA 58.01.02.10.109). Surface water in Idaho is divided into 2,641 water body units, codified in IDAPA 58.01.02.109–160. A water body unit may be divided or split based on information that shows distinct differences within a water body unit, such as changes in land use, local geography or ecosystem. Idaho currently has 5,676 state AUs (and 232 tribal AUs). These AUs are listed in the [Integrated Report, Appendix A](#) (DEQ 2022b).

4.1.1 Fish Tissue Element

The fish only criterion of 8 µg/kg is a direct measure of the concentration of inorganic arsenic in fish tissue that would provide protection for consumers at the Idaho-specific fish consumption rate and cancer risk factor and is the tissue concentration that the water column concentration is intended to protect (Appendix A).

Fish tissue concentration is compared to the criterion based on an average or composite of a *minimum* of five individual fish of the same species, collected from the same water body within the same calendar year, defined as January 1–December 31. When available, game fish species representative of the size and species that may be *legally harvested* within the water body should be used. Species that are not legally harvestable at the time of sampling, or are protected species, should not be collected. All [fishing rules](#) set by Idaho Department of Fish and Game (IDFG) should be followed (IDFG 2023).

The appropriate permits from IDFG (e.g., the [scientific sampling permit](#)) for sampling must be obtained before sampling and should be included in the sampling plan submitted to DEQ. The permit request may include sampling purpose, sampling area, species, sampling method, disposition, and type of samples required. It may take 6 weeks or more for permit approval; and some species of fish, depending on location may not be allowed for sampling. Contact IDFG for more information about sampling permits.

Game fish, defined by rule, are fish routinely pursued by recreational anglers and can be consumed. According to IDFG, the following are fish considered game fish¹: Brook, Brown, Cutthroat, Golden, Lake (Mackinaw), Rainbow (including Steelhead), Splake and Sunapee Trout; trout hybrids (e.g., Tiger Trout); Atlantic, Chinook, Coho, and Kokanee Salmon; Arctic Grayling; Whitefish; Cisco; Crappie; Perch; Bass; Catfish; Bullhead; Sunfish; Northern Pike; Tiger Muskie; Walleye and Saugey; and Burbot (Ling) ([Idaho Fishing Seasons & Rules](#)).

Formatted: Superscript

¹ The fish on the threatened or endangered species are not included.

In the absence of game fish species, other resident fish species may be used. The absence of a minimum of five fish of a single species is considered insufficient fish tissue data, and the water column element (4.3 µg/L) would be the applicable criterion. Results from multiple sample events may be averaged or composited if they represent the same species collected from the same water body within the same calendar year.

The fish tissue criterion can only be used if no new activity or discharge occurs that contributes arsenic to the water body within the prior 90 days.

Multiple species also may be used to evaluate compliance with the criterion, but each sample must contain a minimum of five individuals, and each species sample must be evaluated independently of each other. For example, if five Rainbow Trout and five Mountain Whitefish were collected at a site, that site would have two samples. If the Rainbow Trout sample exceeded the fish tissue criterion, while the Mountain Whitefish sample did not, the criterion would still be considered exceeded. More than five individuals may compose a sample, which can mean multiple sampling events that collect the same species over a calendar year will be evaluated for compliance with the criterion. Multiple sampling events over a calendar year may more accurately capture an annual average value of inorganic arsenic in fish tissue. For example, if during spring sampling five rainbow trout were caught, summer sampling caught six rainbow trout, and fall sampling caught three rainbow trout, all specimens (of the same species and more than the minimum of five individuals), would be averaged and evaluated against the criterion as one value as the annual arithmetic mean.

Fish tissue samples should target harvestable game fish species or other fish species that are commonly consumed by the general public. If a sufficient number of fish are unavailable, the water column criterion of 4.3 µg/L is the applicable criterion. If a sampling plan is developed and the applicant wants to use fish tissue data to ensure compliance with the fish tissue criterion, and suitable game fish are *not* available, according to the rule, other resident fish species may be used; however, ample evidence showing the absence game fish species should be presented by the permit applicant.

4.1.2 Water Column Element

Since fish tissue data are not always available or obtainable, DEQ included a water column element in the fish only recreational criteria. The calculated water column element of 4.3 µg/L dissolved inorganic arsenic is based on the Idaho-specific TL-BAF and is the applicable criterion when sufficient fish tissue data are not available. Although uncertainty exists about the relationship of inorganic arsenic concentrations in the water column and fish tissue (Morrison et al. 2023; DEQ 2020), most measures of the central tendency of inorganic arsenic BAFs in the Idaho inorganic arsenic monitoring study are in the range of 1 to 2 L/kg (DEQ 2020); the TL-BAF of 1.87 L/kg falls within this range (

Equation 2~~Equation-2~~). The resulting water column element of 4.3 µg/L based on the TL-BAF of 1.87 L/kg would protect the recreational use when fish tissue data are unavailable or unobtainable. Appendix A explains criteria developed during rulemaking.

When sampling to monitor for compliance with the criterion, water column samples taken must represent the annual average concentration of dissolved inorganic arsenic at the site. No minimum number of samples is required. The samples will be evaluated as an arithmetic annual mean for compliance; however, seasonal variation should be captured, as much as logistically possible.

4.2 Domestic Water Supply Criterion

Waters designated for DWS must protect humans from harmful levels of inorganic arsenic through both drinking water and fish tissue consumption. According to Idaho's water quality standards, the DWS designation should meet water quality appropriate for use as untreated raw water for public drinking water:

Water quality appropriate for use as untreated raw water (as defined under IDAPA 58.01.08, "Idaho Rules for Public Drinking Water Systems") for public drinking water. (IDAPA 58.01.02.100.03).

The water and fish water column criterion of 10 µg/L is taken from the SWDA MCL for arsenic (EPA 2022b). Waters meeting the DWS water quality criteria also meet SWDA standards, which protect public drinking water systems.

Compliance with the DWS water column criterion is based on an annual arithmetic mean. While no minimum number of samples is required, the mean should represent annual average conditions at the site (i.e., represents seasonal variation). A water body would meet the criteria for water and fish (DWS) exposure to inorganic arsenic if the water column concentration does not exceed 10 µg/L. However, as in all waters in Idaho, the more restrictive criteria apply to a water body. The aquatic life criteria for arsenic are much higher, at 340 µg/L for ~~chronic~~acute, and 150 µg/L for ~~acute~~chronic aquatic life exposures; in water bodies with recreational or DWS designations, the human health criteria would be the more restrictive and applicable criteria.

If a water column translation of the fish only criterion is conducted in a designated DWS stream and the resulting water column value is greater than 10 µg/L, then the DWS criteria is the more sensitive use that must be protected.

As almost all water bodies in Idaho have the existing or designated use of recreation (IDAPA 58.01.02.101.01.a), the fish only criterion is the more restrictive criteria and would apply in most cases. There are no water bodies in the state designated for DWS only, so the DWS criterion will only be the more restrictive criteria when a water column translation (section 4.3) of the fish only criterion is conducted for a total maximum daily load (TMDL) or an Idaho Pollutant Discharge Elimination System (IPDES) permit in a designated DWS stream, and the resulting number is greater than 10 µg/L. In this case, the DWS criterion of 10 µg/L would be the applicable criterion to calculate effluent limits or TMDL targets as it would be considered the more restrictive use criteria.

4.3 Water Column Translation

In developing effluent limits, TMDL targets (i.e., water column targets for fishless waters [section 6]) or remedial actions under the Comprehensive Environmental Response, Compensation, and Liability Act (e.g., applicable or relevant and appropriate requirements) for waters designated for recreational use, the fish tissue element may be translated to a water column value. The translation is determined using a site-specific TL-BAF based on the ratio of total recoverable inorganic arsenic in fish muscle or fillet tissue to dissolved inorganic arsenic in the water column. The site-specific translation is not a site-specific criterion, it translates the fish tissue element to an applicable water column target using both the fish tissue criterion and a site-specific TL-BAF. Site-specific TL-BAF calculations for arsenic will be evaluated and used on a case-by-case basis. DEQ recommends working with the DEQ regional office scientist when developing a sampling methodology. Sampling should be conducted to reflect bioaccumulation processes affected by the upstream water. Both fish tissue and water column samples must meet the requirements of IDAPA 58.01.02.210.03.e.v. DEQ also recommends working with a DEQ regional office scientist when developing a sampling methodology. IDAPA 58.01.02.210.03.e.v.4 for arsenic states “BAFs are calculated as a tropic-level weighted BAF or *other scientifically defensible method for deriving protective BAF.*” If an applicant proposes an alternative method for deriving a protective BAF other than a TL-BAF, they should submit the method rationale for evaluation to DEQ before sampling.

The translation directly incorporates the fish only fish tissue criterion for recreational waters of 8.0 µg/kg but may result in a water column value ~~more-greater than~~ or less ~~stringent~~ than the statewide water column element depending on the site-specific conditions. The translated value becomes the applicable criterion for the specific application (e.g., permit, TMDL, fishless water). If the translated criterion exceeds the water and fish criterion (10 µg /L) in waters also designated for DWS, then the water and fish criterion would apply instead of the translated fish only criterion, as the more stringent use criterion applies (Appendix C).

4.3.1 Water Column Translation Data Requirements

To conduct a water column translation, a site-specific TL-BAF must be calculated. An applicant for a water column translation needs the following:

- Data identifying available fish species at the site, including historical presence data and a fish biologist consultation
- Sampling and quality assurance/quality control (QA/QC) plan
- Paired fish tissue and water column concentrations of inorganic arsenic from all available representative TL (TL2, TL3, TL4) legally harvestable fish species in the water body

Data used to translate the fish tissue element must be based on current conditions. Sampling for a water column translation should develop translation in a spatial and temporal manner consistent with criteria development (e.g., consider annual variation) and collect fish tissue data for TLs 2, 3, and 4. As described in the rule and this guidance, when available, game fish species should be collected and used to develop a TL-BAF; however, other resident nongame fish

species may need to be used for the lower TLs. In the absence of a representative TL fish as confirmed by fish biologist consultation or DEQ and IDFG data, default TL values from the statewide study should be used (Table 4).

In fishless waters, surface water and fish tissue from the immediate downstream waters may be used for bioaccumulation modeling for a target water column value. In the absence of sufficient fish tissue data (IDAPA 58.01.02.210.03.d), the statewide water column element is the applicable criterion element (section 4.1.2).

Permit applicants seeking to develop a site-specific water column translation should consult with DEQ before sampling activities to ensure the appropriate sampling targets and TL-BAF water column translation.

4.3.2 Calculating a Site-Specific Water Column Translation

1. Once paired fish tissue and water column inorganic arsenic data have been procured, calculate BAFs for each species using [Equation 3](#). Each fish tissue sample must be an average or composite of at least five individuals of the same species from the same target water body with paired water column samples collected in the same year. If the minimum number of individuals for a sufficient fish tissue is not available for a species (minimum of five individuals), the sample cannot be used for calculating a site-specific TL-BAF; however, the default BAFs in Table 4 can be used.

$$BAF_{iAs} = \left(\frac{[iAs]_{Fish}}{[iAs]_{Water}} \right)$$

Equation 3. Translation BAF calculation.

Where:

BAF_{iAs} = sample BAF for inorganic arsenic in L/kg

$[iAs]_{Fish}$ = concentration of inorganic arsenic in fish in $\mu\text{g/kg}$

$[iAs]_{Water}$ = concentration of inorganic arsenic in water, in $\mu\text{g/L}$

2. Assign each species to a TL. Use TL assignments from Table 4 or another scientifically defensible method, such as stable isotopic analysis, or consultation with a fish biologist. For missing TLs, the default TL-BAFs should be used. If more than one species exists at a TL, take the geometric mean of the BAFs of that TL. For example, if there are samples of Longnose Sucker (TL2), Rainbow Trout (TL3), Lake Whitefish (TL3), Cutthroat Trout (TL3), and Sauger (TL4), take the geometric mean of the three TL3 BAFs before proceeding. Five fish from a single species per TL is sufficient.
3. Use [Equation 4](#) to calculate the site-specific TL-BAF. If a TL was missing during sampling plan development, after confirmation by DEQ, use the default TL-BAF from Table 4.

$$TL\ BAF = [(BAF_{TL2})(0.36) + (BAF_{TL3})(0.40) + (BAF_{TL4})(0.24)]$$

Equation 4. Translation TL-BAF calculation.

Where:

TL-BAF = trophic level weighted BAF in L/kg

BAF_{TLi} = geometric mean of BAFs calculated for all samples for species assigned to TL_i in L/kg; and the proportion of national fish consumption rate for TL_i fishes (Table 3)

Table 4. TL assignments for calculating TL-BAF.^a

Trophic Level	Species	Rationale	Default Trophic Level Bioaccumulation Factor (L/kg)
2	Sucker ^b (Utah, Largescale, Longnose, Mountain)	Herbivorous	2.99
3	American Shad, Arctic Grayling, Bear Lake Whitefish, Black Bullhead, Blue Catfish, Bluegill, Bonneville Cisco, Brook Trout, Brown Bullhead, Channel Catfish, Common Carp ^b , Cutthroat Trout, Crayfish, Golden Trout, Lake Whitefish, Longnose Dace ^b , Mountain Whitefish, Pumpkinseed, Pygmy Whitefish, Splake Trout, Sculpin ^b , Sunapee Trout, Rainbow Trout, Redside Shiner ^b	Primarily invertivores, or opportunistic invertivore/piscivore where invertebrates make up a large component of diet	1.82
4	Alandic Salmon, Black Crappie, Brown Trout, Burbot, Chinook Salmon, Coho Salmon, Green Sunfish, Lake (Mackinaw) Trout, Largemouth Bass, Northern Pike, Sauger, Smallmouth Bass, Kokanee Salmon, Tiger Trout, Walleye, White Crappie, Yellow Perch	Primarily piscivores, or diet composed mostly of large invertebrates and fishes	0.27

a. Contact DEQ for any species outside of this list.

b. These species are not listed game fish. TL assignments were based on information from Sigler and Zaroban (2018), and Fishbase (www.fishbase.se). Additional data or site-specific species information may be available to determine TL for fish at a sampling location.

Use

4. ~~Equation 5~~Equation 5 to calculate the water column translation based on the fish tissue criterion of 8 µg/kg, resulting in a water column criterion for dissolved inorganic arsenic:

$$WC_T \left(\frac{\mu g}{L} \right) = \frac{8.00 \mu g/kg}{BAF_{SS} L/kg}$$

Equation 5. Water column translation calculation.

Where:

WC_T (µg/L) = translated water column value

BAF_{SS} L/kg = site-specific BAF calculated consistent with IDAPA 58.01.02.210.03.e.v.

4.3.3 Example Water Column Translation Calculation

In this section, an example calculation of the water column translation is provided. For the following paired fish tissue and water column samples, the BAFs for each TL are calculated as fish tissue (in µg/kg) divided by water column (in µg/L), per step 1 in section 4.3.2:

Species	Specimen Count	Trophic Level	Fish (µg/kg)	Water (µg/L)	Resulting BAF (L/kg)
Bridgelip Sucker	5	2	2.3	0.608	3.78

Mountain Whitefish	5	3	2.0	0.583	3.43
Pumpkinseed	5	3	9.4	0.583	16.12
Rainbow Trout	5	3	0.2	0.649	0.31
Brown trout	5	4	0.8	0.608	1.32

After taking the geomean of the three TL3 species BAFs, the following BAFs were obtained for each TL:

Trophic Level	Resulting BAF (L/kg)
2	3.78
3	2.57
4	1.32

To calculate a site-specific TF-BAF, the above TF-BAFs are inserted into [Equation 4](#) (step 3, section 4.3.2), resulting in a TL-BAF of 2.71 L/kg:

$$TL\ BAF = [(3.78L/kg)(0.36) + (2.57L/kg)(0.40) + (1.32L/kg)(0.24)] = 2.71\ L/kg$$

Using the site-specific TL-BAF, the site-specific water column element of 2.95 µg/L is calculated shown below:

$$WC_T \left(\frac{\mu g}{L} \right) = \frac{8.00\ \mu g/kg}{2.71\ L/kg} = 2.95\ \mu g/L$$

5 General Implementation Considerations

Implementation consideration scenarios are found in Appendix B.

5.1 Fish-Tissue Monitoring and Assessment

DEQ recommends engaging early with the agency to develop a sampling and analysis plan before any sampling or monitoring activities occur. Before developing Idaho-specific arsenic criteria, DEQ completed an extensive water column and fish tissue monitoring project and developed the quality assurance project plan (QAPP) [Arsenic Monitoring to Support Human Health Criteria Adoption](#) (DEQ 2019). DEQ recommends referring to this QAPP when developing a plan for arsenic criteria monitoring. A sampling plan should include, at minimum, the following information:

- Location of planned sample site, including Global Positioning System (GPS) coordinates, satellite imagery if possible
- Analysis of resident game fish species present at [the](#) study site
- Planned dates of sampling activity
- Field collection protocol
- QA/QC plan

DEQ encourages permittees in proximity to other permittees or facilities with the same water body to develop cooperative fish tissue monitoring programs in lieu of facility-specific monitoring. If parties are interested in developing a cooperative program, contact DEQ. For those facilities that opt to not participate in the cooperative program, facility-specific ambient fish tissue monitoring may still be required.

5.1.1 Recommended Species

To protect human health through the consumption of fish, legally harvestable game fish are the recommended species for determining compliance and for monitoring and assessment. In the absence of game fish, other resident fish species may be used for monitoring and assessment. Game fish are listed in section 4.1.1 and defined as fish routinely pursued in the evaluated water body.

When developing a plan to target species for monitoring, DEQ recommends working with DEQ and IDFG regional fisheries biologists to determine which species of fish are most prevalently caught and consumed within the target area. Take care when sampling to avoid recently stocked populations of game fish as they have a relatively short period of exposure to ambient conditions. Fish in residence for at least 90-days are assumed to meet the conditions for uptake of ambient arsenic. IDFG provides a comprehensive list of hatcheries and details of locations [where fish are stocked](#) on a statewide basis and [how to identify stocked fish](#). Often hatchery fish have a clipped adipose fin but not always. When developing a monitoring plan, research the location and timing of stocking and avoid those areas and times if possible.

5.1.2 Sampling Assessment

Fish tissue and water column samples must be analyzed for inorganic arsenic using sensitive analytical methods that provide sufficient detection limits to quantify inorganic arsenic at levels necessary for the proposed application. For example, EPA method 1632, which was used for developing the statewide criteria, has a method detection limit of 0.003 µg/L for water samples (EPA 1998). For the analysis, the skin of the fish tissue sample was removed to develop the statewide fish tissue criterion.

Other analytical methods may be used for the assessment, as long as the method can report concentrations of inorganic arsenic below the applicable criterion. Include these methods in the sampling plan submitted to DEQ for approval before implementation.

5.1.3 Spatial Considerations

The spatial extent of a sampling or monitoring plan must be defined and factors that may affect arsenic variability throughout the site must be identified so they can be considered in the sampling plan design (EPA 2021b).

When sampling a site, GPS coordinate locations should be taken for the downstream and upstream limits of the site, or the beginning and end of where the samples were taken. For water column sampling, the goal is downstream of a discharge and as close as reasonable to

the discharge that is representative and considers mixing between the discharge and the receiving water body. The location of water column sampling should also be recorded on a GPS device.

When sampling for fish tissue, consider which fish in the site are targeted for recreational fishing and are usually consumed. For water column sampling, the flow characteristics of the water body sampled, along with the locations where fish are feeding and spawning, should be considered. Attempt to sample all habitat types to appropriately characterize the range and distribution of arsenic concentrations at a site. Adjust monitoring plans to include species of fish found in the small stream segment and consider the relationship of upstream sources to downstream habitats (EPA 2018).

Sampling reaches should be identified based on existing fish habitat, known presence of fish, and proximity to discharge. The determination of this reach should be clearly described in the sampling plan. Lengths of a sampling reach may vary based on site parameters but maintain consistency between each sample site. Idaho's *Beneficial Use Reconnaissance Program (BURP) Field Manual* (DEQ 2017a) defines a reach as 30 times the full bank width or a minimum of 100 meters long. Upstream and downstream ends should be established and marked using a GPS device.

The level of spatial representation of sampling to implement the arsenic criteria for human health depends on how the data are to be used—whether monitoring results will be used to develop effluent limits for IPDES permits, or to determine compliance with water quality standards for the Integrated Report, IPDES permits, TMDLs, or remediation efforts. In flowing waters, spatial representation is generally ensured by sampling well-mixed portions of the stream (i.e., sampling from the thalweg and avoiding confluences or other obvious lateral inputs) (DEQ 2020).

5.1.4 Temporal Considerations

According to IDAPA 58.01.02.210.3.e.v.3, “water column samples must be representative of the annual average concentration of dissolved inorganic arsenic at the site.” When building a sampling plan, take sampling frequency and quantity into consideration for sites where the water column may have seasonal changes, such as spring melt/runoff.

A fish tissue sample is a composite of a *minimum* of five individual fish of the same species over a calendar year. Since a single sample can be composed of five or more individuals of a species over a calendar year, it may be beneficial to incorporate multiple sampling events in the sampling plan. Particularly for developing TL-BAF water column translations, a more annual representative sampling plan may be needed.

For a TMDL or IPDES permit, develop a sampling plan to determine how many samples will be taken and how often to satisfy the requirements in the rule. For nonpoint source activities, one sample taken yearly that does not exceed criteria may be enough to satisfy the criteria, but frequency requirements are evaluated on a case-by-case basis by the permit writer.

6 Fishless Waters

Fishless streams are defined as the streams, or stream reaches:

- With insufficient instream habitat and/or flow to support a population of one or more fish species on a continuing basis
- Where fish are naturally absent due to ephemeral, intermittent, or persistent low flows
- Streams that lack a permanent connection to downstream fish-bearing waters

If a water body does not support fish because of unnatural conditions, such as presence of pollutants, then use the water column element (section 4.1.2).

In waters that meet the definition of fishless, the water column element may be used, or surface water and fish tissue from the immediate downstream waters may be used for bioaccumulation modeling for site-specific water column translation (section 4.3). To determine that a water body is fishless, the site should have accompanying research and field data that is less than 5 years old. DEQ recommends using either electrofishing or environmental DNA of the site to collect comprehensive data for all species (DEQ 2022a). In the absence of sufficient fish tissue data, the water column element is the applicable criterion. When fish tissue samples are not available in the nearest water body from the project location, or several tributaries contribute to the system before fish availability, the water column element is the applicable criterion (section 4.1.2).

Fishless Waters

Fish from the immediate downstream can only be used for bioaccumulation modeling to develop a site-specific water column translation.

The following factors are considered in any sampling plan aimed at understanding bioaccumulation dynamics in a downstream water affected by upstream sources:

- Variation (e.g., low-to-high exposure depending on location and time) in fish arsenic exposure from other waters in addition to the upstream fishless water
- Spatial Variability, ~~both spatial and seasonal~~, of arsenic concentrations in surface waters and fish tissue
- Timing and location of sampling of water and fish to be representative of this variability

7 Identifying Impairments for Integrated Report

The process of assessing whether a water body fully supports beneficial uses is governed by IDAPA 58.01.02.054. DEQ uses the *Water Body Assessment Guidance* (DEQ 2016a) as a guide to make assessment decisions. Under IDAPA 58.01.02.054, data used for assessing compliance with the arsenic criteria in the Integrated Report should represent the AU assessed. When evaluating arsenic data to determine compliance with criteria for the Integrated Report, DEQ assessors use the following approach (DEQ 2022b):

- For contact recreational use criteria, if fish tissue data from at least five individuals of the same species within the same calendar year are available, compare the fish tissue data results to the applicable tissue criterion element (fish only). If the fish tissue value is less than the criterion, the AU is not listed as impaired. If any fish tissue sample, as defined in IDAPA 58.01.02.210.03.d and described in this guidance, exceeds the criterion, the AU is listed as not full support/impaired.
- If fish tissue data is not available, compare water column data to the water column criterion element. If the annual arithmetic mean of the water column data exceeds the criterion, the AU is listed as not full support/impaired.
- If a water column translation was performed, and water column samples taken exceed the translated value during monitoring or routine sampling, the AU is listed as not full support/impaired.

If a water body exceeds the applicable criterion, the water body will be listed on the CWA § 303(d) list according to evaluation standards established in the *Water Body Assessment Guidance* (DEQ 2016a). For waters designated for contact recreation, DEQ uses data less than 5 years old to determine a water body is not fully supporting when there are any exceedances of the appropriate criteria. For DWS, DEQ evaluates existing and readily available surface water data (e.g., from DEQ or US Geological Survey) to identify any exceedance of criteria values.

8 Antidegradation

Idaho's antidegradation policy maintains the existing quality of Idaho waters. The objective of Idaho's antidegradation rule (IDAPA 58.01.02.051) is to review point source discharge activities and provide the necessary level of protection. The implementation of the policy is addressed in IDAPA 58.01.02.052 and in the *Idaho Antidegradation Implementation Procedures* (DEQ 2019b). The statutory policy on antidegradation consists of three tiers of protection as required by federal rule (Idaho Code § 39-3603). Each level, or tier, has its own requirements for protecting water quality. Tier I is the minimum level of protection and requires that existing uses be met. Tier II is the middle level of protection and ensures degradation is "necessary to accommodate important economic or social development" (IDAPA 58.01.02.051.02). Degradation is not prohibited, but it must be necessary and justified. Tier III is the highest level of protection, reserved for waters of outstanding character (outstanding resource waters), defined as "high quality water, such as water of national and state parks and wildlife refuges and water of exceptional recreational or ecological significance, which has been designated by the legislature" and subsequently listed in IDAPA 58.01.02.010.72. No degradation of water quality is permitted in these waters.

Antidegradation review is triggered by an application for a new or reissued permit or license, including IPDES discharge permits or any federally permitted or licensed activity (e.g., Army Corps of Engineers CWA § 404 dredge and fill permits, and Federal Energy Regulatory Commission [FERC] licenses) where a § 401 water quality certification is required. For IPDES permits, the antidegradation analysis is integrated into the permit as described in section 10.1.

9 Clean Water Act § 401 Water Quality Certifications

The CWA § 401 water quality certification process is triggered when a discharge to waters of the state subject to CWA jurisdiction is proposed, and a permit or license is required for the activity. Some of the major federal licenses and permits subject to § 401 include the following:

- CWA § 402 and § 404 permits issued by EPA or the Army Corps of Engineers
- FERC licenses for hydropower facilities and natural gas pipelines
- Rivers and Harbors Act Section 9 and 10 permits.

The Idaho § 401 certification process is detailed in the 2021 *Idaho Section 401 Certification Guidance* (DEQ 2021b). For certifications with possible arsenic discharge, it is possible that during the § 401 certification process, a project proponent may be required to monitor fish tissue concentrations and/or dissolved inorganic arsenic in receiving waters. The water column translation may not be used where collecting fish tissue data before the certification request is not feasible. In that case, the certification writer should use the statewide water column or fish tissue criteria.

Most activities that are permitted under the § 404 program and certified by DEQ are not likely to be considered degrading because of their short-term duration and the understanding that arsenic increases resulting from temporary discharges will eventually equilibrate. Unlike other metals, such as mercury and selenium, inorganic arsenic is not highly bioaccumulative. Little concern exists that small, nonlasting changes in water chemistry would result in significant changes in fish tissue.

Some in-water work, including dredging projects, may be considered degrading, and DEQ may require the applicant to use the Sediment Evaluation Framework, perform a pilot test characterization of the proposed discharge, or perform other actions to determine whether degradation will occur. The certification writer will use best professional judgement when making such a determination, and the decision will be explained in the certification.

When an affected water body is unassessed, the applicant has the option to voluntarily acknowledge that the water body may be considered high quality and agree to the agency implementing Tier II protection. If the applicant does not believe the water body is high quality, DEQ must use information available to make a determination.

All relevant information available will be used to determine the appropriate level of antidegradation protection, including new information generated during the application process to specifically address the question of whether the water is high quality. New information may come from DEQ, other agencies, organizations, companies, or individuals. According to IDAPA 58.01.02.052.08(a)(ii), DEQ may ask the applicant to gather information to help with this determination.

10 TMDL Process

For AUs placed on the CWA § 303(d) list as Category 5 waters due to exceedances of arsenic criteria, development of a TMDL is required. The TMDL process for arsenic will follow and be as consistent as possible with existing federal and Idaho's *Guidance for the Development of Total Maximum Daily Loads* (DEQ 1999). TMDLs for arsenic are prepared using a standard process: subbasin assessment, loading analysis, and implementation plan. The following sections discuss arsenic-specific considerations for the TMDL process.

10.1 Subbasin Assessment

The subbasin assessment is the initial section of the TMDL that describes the elements necessary to characterize the watershed. Typical TMDLs focus on source identification and pollutant control efforts in the watershed.

Present physical and biological characteristics, such as native arsenic deposits and formations should be included in this section. Fishery identification (including anadromous use and other native/nonnative species caught for recreational uses) is required, and regional IDFG offices should be consulted for fish species information for specific water bodies. Cultural characteristics should also be summarized, including the location of point and nonpoint sources in the watershed. Potential sources of arsenic to water bodies in Idaho include the following:

- Direct discharges of arsenic from water point sources
- Runoff from current or legacy mining sites or mining wastes, and other waste disposal sites, such as landfills
- Sediments that may have arsenic contamination or hot spots resulting from past discharges or historical placer mining activities.
- Geologic or *naturally occurring* arsenic in soils

10.2 Loading Analysis

Loading analysis estimates a water body's pollutant load capacity, margin of safety, and allocations of load to pollutant sources defined as the TMDL in EPA regulations (DEQ 1999; 40 CFR 130.2). Load capacity is the maximum quantity of a pollutant a water can receive and still meet water quality standards. Federal regulations allow that "loads may be expressed as mass per unit time, toxicity, or other appropriate measures" (40 CFR 130.2(l)). TMDL targets and subsequent load and waste load allocations (WLAs) for arsenic are based on statewide water column or fish tissue criteria or site-specific water column criteria, where applicable. Arsenic TMDLs are expected to lead to attainment of fish tissue criteria when the water column ~~selenium~~-arsenic criteria are achieved. Natural background contributions, which are likely present for arsenic, are considered part of the load allocation but are often treated separately because they represent a part of the load not subject to control.

Seasonal variations are also typically included in TMDL determinations. For example, one TMDL applies during the summer and another TMDL applies during the winter. These variations

enable a translation between the end-point for the TMDL (expressed as a fish tissue concentration of arsenic) and the arsenic loads to the water (expressed in water column loads).

Setting numeric limits when no feasible means exist to meet these limits creates major compliance issues that must be addressed using lengthy and expensive site-specific options such as variances. TMDL writers should reasonably consider the relative contribution of each source as one factor in developing allocations. Under current guidance, when a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on the assumption of reductions in the nonpoint sources, the TMDL should provide reasonable assurance that nonpoint source control measures will achieve expected reductions. This concept is also reflected in the definition of a TMDL, which allows for less stringent WLAs when best management practices or other nonpoint source controls make more stringent load allocations practical (40 CFR 130.2(i)). IPDES permit conditions will include monitoring, arsenic-control best management practice approaches, and other feasible treatment improvements.

11 Idaho Pollutant Discharge Elimination System

The CWA prohibits point source activities that discharge pollutants to waters of the United States unless a permit is obtained. DEQ has authority to issue CWA § 402 discharge permits in Idaho through the IPDES Program. Several guidance documents are available on IPDES Program implementation.

To meet the state's EPA-approved standards as required in the CWA § 301(b)(1)(C) and Idaho IPDES regulations (IDAPA 58.01.25), permit writers develop water quality-based effluent limits (WQBELs) if reasonable potential to exceed (RPTE) standards have been demonstrated.

Effluent data requirements recommended for toxics or hazardous pollutants are found in section 3.3 of EPA's *Technical Support Document for Water Quality-based Toxics Control* (EPA 1991). Other IPDES monitoring guidance should be used to identify appropriate monitoring requirements for RPTE determinations and IPDES permitting. These resources can be used to assess whether the discharge meets the RPTE water quality criteria to cause or contribute to an instream excursion above the water column element for arsenic criterion. Because arsenic monitoring data (both effluent and ambient) in Idaho is scarce, IPDES permitting strategies are expected to evolve as additional monitoring data become available. Effluent limits in IPDES permits are designed to control all pollutants or pollutant parameters (i.e., conventional, nonconventional, or toxic pollutants) that are or may be discharged at a level that will cause, have the reasonable potential to cause, or contribute to an excursion above any state water quality standard including state narrative criteria for water quality (IDAPA 58.01.25.103).

Through the permitting process, a permittee may be required to monitor fish tissue or water column concentrations in the receiving water body, in addition to monitoring total recoverable arsenic (i.e., where DWS is a protected use), and/or dissolved inorganic arsenic (i.e., where recreation is a protected use).

IPDES regulations require permit writers to assess the impact of discharges to evaluate downstream water quality. Recommended permit conditions for effluent limits depend on whether the sources will cause or contribute to a violation of the water quality criteria. To determine if inorganic arsenic has the potential to cause a water quality violation, several sources of information and methods can be used such as site visits, historical information, or monitoring data if available. The permit must contain effluent limits to control all pollutants that have a RPTE water quality criterion (IDAPA 58.01.25.302.06.i):

Effluent limitations in a permit must control all pollutants or pollutant parameters (either conventional, nonconventional, or toxic pollutants) which the Department determines are or may be discharged at a level which will cause, have the reasonable potential to cause, or contribute to an excursion above any water quality standard, including narrative criteria for water quality.

Similar to other parameters, certain facilities that have very little potential to discharge arsenic may not include arsenic as a pollutant of concern during the permit development process. Examples include facilities that discharge noncontact cooling water without additives. This determination may be based on available data, surrogate facility monitoring (e.g., if another facility for an industrial company uses the same processes and available arsenic monitoring data indicate no arsenic is discharged), other literature information, or best professional judgment in the absence of such information.

The other situation where a facility may receive special consideration is when the sole source of arsenic in the effluent occurs from the intake water, and the facility discharges to the intake source water body. In this case, the facility should consult with its permit writer to consider options for regulatory relief (e.g., intake credit in IDAPA 58.01.25.303.07). Typically, where a pollutant of concern is present in the effluent, the permit will require monitoring.

11.1 Reasonable Potential to Exceed

To meet the state's EPA-approved standards as required in the CWA § 301(b)(1)(C) and Idaho IPDES regulations (IDAPA 58.01.25), permit writers develop WQBELs if RPTE standards have been demonstrated.

If arsenic is a pollutant of concern, a permittee can determine if an RPTE exists for the arsenic human health criteria by using representative fish tissue or water column data collected as prescribed in section 4.1. Where representative fish tissue data cannot be obtained, or in fishless waters, the water column criterion is the applicable criterion and is the basis for determining RPTE and deriving effluent limits.

The RPTE process is used to determine necessity of effluent limitations for arsenic. For facilities with the potential to discharge arsenic, the permit writer will use best professional judgement to determine the level of RPTE analysis required.

11.2 Establishing Permit Conditions

Each permit includes sections to characterize the effluent and receiving water body. The permit writer follows the IPDES guidance documents to establish permit conditions (DEQ 2017b) according to the “Rules Regulating the Idaho Pollutant Discharge Elimination System Program” (IDAPA 58.01.25), and other applicable IPDES guidance. For arsenic, the process involves the following steps:

1. Assess the reliability of available water quality data, both water column and fish tissue concentrations, as available. If arsenic data are not available, then the facility is required to monitor arsenic during the next permit cycle. If arsenic data are available, these data should be used to calculate the RPTE.
2. Determine the RPTE using available fish tissue monitoring data. If fish tissue data are available, those data are compared against 8 µg/kg. If water column data is used, then those data are compared against 4.3 µg/L. If fish tissue concentrations exceed this threshold, then RPTE is present for all significant dischargers. If the fish tissue concentrations are below the threshold, then no RPTE is present. Less stringent permit conditions may be specified.
3. If fish are present in the receiving water, but sufficient fish tissue data is not available, or in fishless waters, collect water column data to compare to the statewide water column criteria to determine RPTE.
4. Determine need for TMDL (if water body is not already listed). If fish tissue data from the watershed indicate that a single permittee is responsible for elevated concentrations, then permit conditions will be required for that significant source. If multiple sources are present, then the TMDL process should be initiated.

References

- ATSDR (Agency for Toxic Substances and Disease Registry). 2007a. *Toxicological Profile for Arsenic*. Atlanta, GA: US Department of Health and Human Services, Public Health Service. DOI: 10.15620/cdc:11481.
- ATSDR (Agency for Toxic Substances and Disease Registry). 2007b. *Public Health Statement, Arsenic*. Atlanta, GA: US Department of Health and Human Services, Public Health Service. CAS# 7440-38-2.
- ATSDR (Agency for Toxic Substances and Disease Registry). 2009. *What is Arsenic?* Atlanta, GA: US Department of Health and Human Services, Public Health Service.
- Arnot, J.A. and F.A.P.C. Gobas. 2006. "A Review of Bioconcentration Factor (BCF) and Bioaccumulation Factor (BAF) Assessments for Organic Chemicals in Aquatic Organisms." *Environmental Reviews* 14(4): 257–297.
- Brusseau, M.L. and J.F. Artiola. 2019. "Chapter 12, Chemical Contaminants." *Environmental and Pollution Science*. 3rd ed. <https://doi.org/10.1016/B978-0-12-814719-1.00012-4>.
- Chen, L. et al. 2018. "Effects of Acclimation on Arsenic Bioaccumulation and Biotransformation in Freshwater Medaka *Oryzias latipes* after Chronic Arsenic Exposure." *Environmental Pollution*. 238: 17–25. doi.org/10.1016/j.envpol.2018.03.011.
- Chung J.Y., S.D. Yu, Y.S. Hong. 2014. "Environmental Source of Arsenic Exposure." *J Prev Med Public Health* 47(5): 253–257. [doi: 10.3961/jpmph.14.036](https://doi.org/10.3961/jpmph.14.036).
- Cui, Di, et al. 2020. "The Dynamic Changes of Arsenic Biotransformation and Bioaccumulation in Muscle of Freshwater Food Fish Crucian Carp during Chronic Dietborne Exposure." *Journal of Environmental Sciences* 100: 74–81. [doi:10.1016/j.jes.2020.07.005](https://doi.org/10.1016/j.jes.2020.07.005).
- CLU-IN (Contaminated Site Clean-Up Information). 2022. *Arsenic, Occurrence*. US Environmental Protection Agency, Technology Innovation and Field Services Division. <https://clu-in.org/contaminantfocus/default.focus/sec/arsenic/cat/occurrence/>
- DEQ (Idaho Department of Environmental Quality). 1999. *Guidance for Development of Total Maximum Daily Loads*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2016a. *Water Body Assessment Guidance*. 3rd ed. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2016b. *Water Quality Pollutant Trading Guidance*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2017a. *Beneficial Use Reconnaissance Program Field Manual for Streams*. Boise, ID: DEQ.

- DEQ (Idaho Department of Environmental Quality). 2017b. *Idaho Pollutant Discharge Elimination System, Effluent Limit Development Guidance*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2019a. *Arsenic Monitoring to Support Human Health Criteria Adoption (QAPP)*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2019b. *Idaho Antidegradation Implementation Procedures*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2020. *2019 Arsenic Accumulation in Fish Tissue: Preliminary Monitoring Results*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2021a. *Arsenic Human Health Criteria*. Rulemaking Docket 58-0102-1801. Discussion Paper #3. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2021b. *Idaho Section 401 Certification Guidance*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2022a. *Beneficial Use Reconnaissance Program 2022 Annual Work Plan*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2022b. *Idaho's 2022 Integrated Report*. Boise, ID: DEQ.
- DEQ (Idaho Department of Environmental Quality). 2023. *Contaminants in Drinking Water, Contaminants of Interest, Arsenic*. <https://www.deq.idaho.gov/water-quality/drinking-water/contaminants-in-drinking-water/>.
- EPA (US Environmental Protection Agency). 1991. *Technical Support Document for Water Quality-based Toxics Control*. Washington, DC: Office of Water.
- EPA (US Environmental Protection Agency). 1998. *Method 1632 Chemical Speciation of Arsenic in Water and Tissue by Hydride Generation Quartz Furnace Atomic Absorption Spectrometry*. Washington, DC: Engineering and Analysis Division (4303).
- EPA (US Environmental Protection Agency). 2000. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health*. Washington, DC: Office of Water. EPA-822-B-00-004.
- EPA (US Environmental Protection Agency). 2003. *Technical Summary of Information Available on the Bioaccumulation of Arsenic in Aquatic Organisms*. Washington, DC: Office of Water. EPA-822-R-03-032.
- EPA (US Environmental Protection Agency). 2014. *Estimated Fish Consumption Rates for the U.S. Population and Selected Subpopulations (NHANES 2003–2010): Final Report*. Washington, DC: EPA. EPA-820-R-14-002.

- EPA (US Environmental Protection Agency). 2015. *Human Health Ambient Water Quality Criteria: 2015 Update Factsheet*. Washington, DC: Office of Water. EPA 820-F-15-001.
- EPA (US Environmental Protection Agency). 2016. *A Fish Consumption Survey of the Nez Perce Tribe, Final Report*. Vol. II. EPA Contract EP W14 020 Task Order 10.
- EPA (US Environmental Protection Agency). 2018. *Technical Support for Fish Tissue Monitoring for Implementation of EPA's 2016 Selenium Criterion. Draft*. Washington, DC: EPA, Office of Water. EPA-820-F-16-007.
- EPA (US Environmental Protection Agency). 2021a. *Arsenic Compounds*. EPA Hazard Summary Factsheet. https://www.epa.gov/sites/default/files/2021-04/documents/arsenic_april_2021.pdf.
- EPA (US Environmental Protection Agency). 2021b. *Technical Support for Fish Tissue Monitoring for Implementation of EPA's 2016 Selenium Criterion, Draft*. Washington, DC: EPA Office of Water. EPA 823-D-21-002.
- EPA (US Environmental Protection Agency). 2022a. *pH, Overview*. Caddis Volume 2. <https://www.epa.gov/caddis-vol2/ph>.
- EPA (US Environmental Protection Agency). 2022b. *Drinking Water Requirements for States and Public Water Systems, Chemical Contaminant Rules*. <https://www.epa.gov/dwreginfo/chemical-contaminant-rules>.
- EPRI (Electric Power Research Institute). 2008. *Evaluation of U.S. Environmental Protection Agency's Arsenic Ambient Water Quality Criteria: Speciation and Bioaccumulation Issues, Technical Update December 2008*. Document ID 1015570.
- EPRI (Electric Power Research Institute). 2011. *Evaluation of U.S. Environmental Protection Agency's Arsenic Ambient Water Quality Criteria: Speciation and Bioaccumulation Issues, Technical Update December 2011*. Document ID 1021822.
- Faria, Márcia Cristina da Silva, et al. 2023. "Arsenic in Mining Areas: Environmental Contamination Routes." *International Journal of Environmental Research and Public Health* 20(5): 4291. <https://doi.org/10.3390/ijerph20054291>.
- Froese, R. and D. Pauly, eds. 2000. *FishBase 2000: Concepts, Design and Data Sources*. ICLARM, Los Baños, Laguna, Philippines.
- Gorny, J., et al. 2015. "Arsenic Behavior in River Sediments Under Redox Gradient: A Review." *Science of the Total Environment* 505: 423–434. <http://dx.doi.org/10.1016/j.scitotenv.2014.10.011>.
- Ghosh, D., A. Ghosh, and P. Bhadury. 2022. "Arsenic Through Aquatic Trophic Levels: Effects, Transformations and Biomagnification—A Concise Review." *Geosci. Lett.* 9(20). <https://doi.org/10.1186/s40562-022-00225-y>.

- IDFG (Idaho Department of Fish and Game). 2023. *Idaho Fishing 2022-2024 Seasons & Rules*. 2nd ed. <https://idfg.idaho.gov/sites/default/files/seasons-rules-fish-2022-2024.pdf>.
- IDWR (Idaho Department of Water Resources). 2002. *Arsenic Results from the Statewide Program, 1991-2001, Technical Summary*. Boise, ID: IDWR.
- IRIS (Integrated Risk Information System). 2017. *Arsenic, Inorganic*. IRIS Assessments, CASRN 7440-38-2, DTXSID40233886.
- Khosravi-Darani, K.; Y. Rehman; Y.A. Katsoyiannis; E. Kokkinos; A.I. Zouboulis. *Arsenic Exposure via Contaminated Water and Food Sources*. *Water* 2022, **14**, 1884. <https://doi.org/10.3390/w14121884>
- Mackay, D., et al. 2013. "Mathematical Relationships Between Metrics Of Chemical Bioaccumulation In Fish." *Environmental Toxicology and Chemistry* 32(7): 1459–1466.
- Morrison, E.B., J. Pappani, A. Prouty, H.M. McChesney, and P.D. Anderson. 2023. "Inorganic Arsenic Concentration in Idaho Fish Tissue Governed by Trophic Level and Size, ~~Not~~^{not} Water Column Concentration: Implications for Human Health Water Quality Criteria." *Environmental Toxicology and Chemistry*. <https://doi.org/10.1002/etc.5626> 42(7): 1542-1552.
- NRC (National Research Council). 1977. "Chapter 3, Distribution of Arsenic in the Environment." *Arsenic: Medical and Biologic Effects of Environmental Pollutants*. US Committee on Medical and Biological Effects of Environmental Pollutants. Washington DC: National Academies Press (US).
- National Water Quality Monitoring Council. 2022. *Arsenic, Inorganic Arsenic, Surface Water, Idaho, 01-01-2012 to 12-31-2022*. Water Quality Portal. <https://www.waterqualitydata.us/#statecode=US%3A16&sampleMedia=Water&characteristicName=Arsenic&characteristicName=Arsenic%2C%20Inorganic&startDateLo=01-01-2012&startDateHi=12-31-2022&mimeType=xlsx&dataProfile=resultPhysChem&providers=NWIS&providers=STEWARDS&providers=STORET>.
- NTP (National Toxicology Program). 2021. *Arsenic and Inorganic Arsenic Compounds. Report on Carcinogens*. 15th ed. Washington, DC: US Department of Health and Human Services. CAS No. 7440-38-2.
- Rahman, M.A., H. Hasegawa, and R.P. Lim. 2012. *Bioaccumulation, Biotransformation and Trophic Transfer of Arsenic in the Aquatic Food Chain*. *Environmental Research* 116: 118–135. ISSN 0013-9351. <https://doi.org/10.1016/j.envres.2012.03.014>.
- Shah, A.Q., et al. 2008. "Accumulation Of Arsenic in Different Fresh Water Fish Species – Potential Contribution to High Arsenic Intakes." *Food Chemistry* 112: 520–524. [doi:10.1016/j.foodchem.2008.05.095](https://doi.org/10.1016/j.foodchem.2008.05.095).

- Sigler, J.W. and D.W. Zaroban. 2018. *Fishes of Idaho: A Natural History Survey*. Caldwell, ID: Caxton Press.
- Simpson, J.C. and R.L. Wallace. 1982. *Fishes of Idaho*. Moscow, ID: University Press of Idaho.
- Ventura-Lima J, Bogo MR, Monserrat JM. Arsenic toxicity in mammals and aquatic animals: a comparative biochemical approach. *Ecotoxicol Environ Saf*. 2011 Mar;74(3):211-8. doi: 10.1016/j.ecoenv.2010.11.002. Epub 2010 Nov 26. PMID: 21112631. Wallace, R.L. and D.W. Zaroban. 2013. *Native Fishes of Idaho*. Bethesda, MD: American Fisheries Society.
- Williams, L., et al. 2006. *Arsenic Bioaccumulation in Freshwater Fishes*. Human and Ecological Risk Assessment, 12: 904-923. DOI: 10.1080/10807030600826821
- WHO (World Health Organization). 2019. *Exposure to Arsenic: A Major Public Health Concern*. WHO/CED/PHE/EPE/19.4.1.
- Zhang, W. et al. 2022. *Arsenic Bioaccumulation and Biotransformation in Aquatic Organisms*. *Environment International* 163: 107221. <https://pubmed.ncbi.nlm.nih.gov/35378441/>.

Appendix A. Formulas Used to Develop the Arsenic Rule

Trophic-Level Weighted BAF

A TL-BAF uses TL-specific proportions from the national fish consumption rate.

$$\text{TL BAF} = [(\text{BAF}_{\text{TL2}})(P_{\text{TL2}}) + (\text{BAF}_{\text{TL3}})(P_{\text{TL3}}) + (\text{BAF}_{\text{TL4}})(P_{\text{TL4}})]$$

TL- BAF calculation.

Where:

TL-BAF = trophic level weighted BAF

BAF_{TLi} = geometric mean of BAFs calculated for all samples for species assigned to TL_i ; P_{TLi} = proportion of national fish consumption rate for TL_i fishes

Thus, using the geometric mean BAFs and TL consumption rate proportion inputs from Table 2 and Table 3 (Section 3.1 of document) , resulting in a TL-BAF of 1.87 L/kg:

$$\text{TL BAF} = [(2.99 \text{ L/kg})(0.36) + (1.82 \text{ L/kg})(0.40) + (0.27 \text{ L/kg})(0.24)] = 1.87 \text{ L/kg}$$

Results for TL BAF calculations.

Human Health Water Quality Criteria for Arsenic

The HHC calculation calculates an ambient water quality criterion for the exposure to inorganic arsenic through fish consumption using the equation factor inputs in the table below.

$$\text{AWQC} = \text{RSD} * \left(\frac{\text{BW}}{\text{DI} + (\text{FI} * \text{BAF})} \right) * 1,000 \text{ } \mu\text{g/mg}$$

Fish only ambient water quality criterion calculation.

Where:

AWQC_{FO} = ambient water quality criterion, fish only exposure

RSD = risk-specific dose (mg/kg-day) derived from a cancer slope factor (chemical specific value) and a target incremental cancer risk

BW = human body weight (kg)

FI = fish intake (kg/day)

BAF = bioaccumulation factor (L/kg)

1,000 $\mu\text{g/kg mg}$ = a conversion factor to convert criteria in units of $\mu\text{g/L}$

Equation factors used in human health criteria calculation for arsenic.

Exposure Factors	
Target Incremental Cancer Risk	1x 10 ⁻⁵
Body Weight	80 kg
Fish Intake	0.0665 kg/day

Chemical Specific Factors	
Inorganic Arsenic Cancer Slope Factor	1.5 (mg/kg-day) ⁻¹
TL-Weighted BAF	1.87

The fish intake value was derived from an Idaho tribal fish consumption survey conducted in 2015. The Nez Perce Tribe, Group 2 (near coastal, estuarine, freshwater, and anadromous finfish and shellfish) mean consumption rate of 0.0665 kg/day has been applied (EPA 2016). Mean body weight was taken from the 2015 EPA human health exposure inputs for human health ambient water quality criteria (EPA 2015a).

Fish Tissue Criterion

The fish only exposure equation produces a value for the water column concentration. This fish tissue criterion value is a direct measure of the concentration of inorganic arsenic in fish tissue that would provide protection for consumers at the Idaho specific fish consumption rate and cancer risk factor.

$$AWQC_{FO} = RSD * \left(\frac{BW}{(FI * BAF)} \right) * 1,000 \mu\text{g}/\text{mg}$$

Fish tissue criterion calculation.

Where:

$AWQC_{tissue}$ = fish tissue criterion for inorganic arsenic in muscle, or fillet, tissue on a wet weight basis

RSD = risk-specific dose based on a target incremental cancer risk of 1×10^{-5} and a cancer slope factor for inorganic arsenic of $1.5 \text{ (mg/kg-day)}^{-1}$

BW = mean adult body weight of 80 kg

FI = fish consumption rate of 0.0665 kg/day

1,000 $\mu\text{g}/\text{kg mg}$ = conversion factor to convert criteria in units of $\mu\text{g}/\text{kg}$

The calculated fish tissue criterion of $8.0 \mu\text{g}/\text{kg}$ is a direct measure of the exposure of Idaho fish consumers to inorganic arsenic. It is a scientifically sound calculation based on Idaho-specific exposure factors for fish consumption and will ensure fish tissue concentrations do not expose consumers to inorganic arsenic in fish tissue that would lead to an increased risk of cancer beyond the selected target incremental cancer risk factor.

Appendix B. Example Scenarios for Applying Human Health Criteria for Arsenic.

1) Recreational use waters with fish.

a) *Water column data available and fish tissue data available.*

- i) The water column criterion element is met, and the fish tissue criterion element is met.
 - (1) Continued collection of water column data (not fish tissue data) can be used to demonstrate continued compliance.
- ii) The water column criterion element is not met, and the fish tissue criterion element is met.
 - (1) Continued collection of fish tissue data can be used to demonstrate continued compliance, or a water column translation value can be developed using a site-specific TL-BAF and continuing compliance demonstrated using water column data.
- iii) The water column criterion element is met, and the fish tissue criterion element is not met.
 - (1) Water body is not in compliance with the recreational use criterion element.
- iv) The water column criterion element is not met, and the fish tissue criterion element is not met.
 - (1) Water body is not in compliance with the recreational use criterion element.

b) *Water column data available, fish tissue data have not been collected but can be collected.*

- i) The water column criterion element is met.
 - (1) Continued collection of water column data (not fish tissue data) can be used to demonstrate continued compliance.
- ii) The water column criterion element is not met; collection of fish tissue data can be used to determine compliance.
 - (1) If fish tissue data are collected and the fish tissue criterion element is met, continued collection of fish tissue data can be used to demonstrate continued compliance, or a water column translation value can be developed using a site-specific TL-BAF and continuing compliance demonstrated using water column data.
 - ~~(1)~~ (2) If fish criterion element is not met; ~~W~~water body is not in compliance with the recreational use criterion element.

2) DWS and recreational use waters with fish.

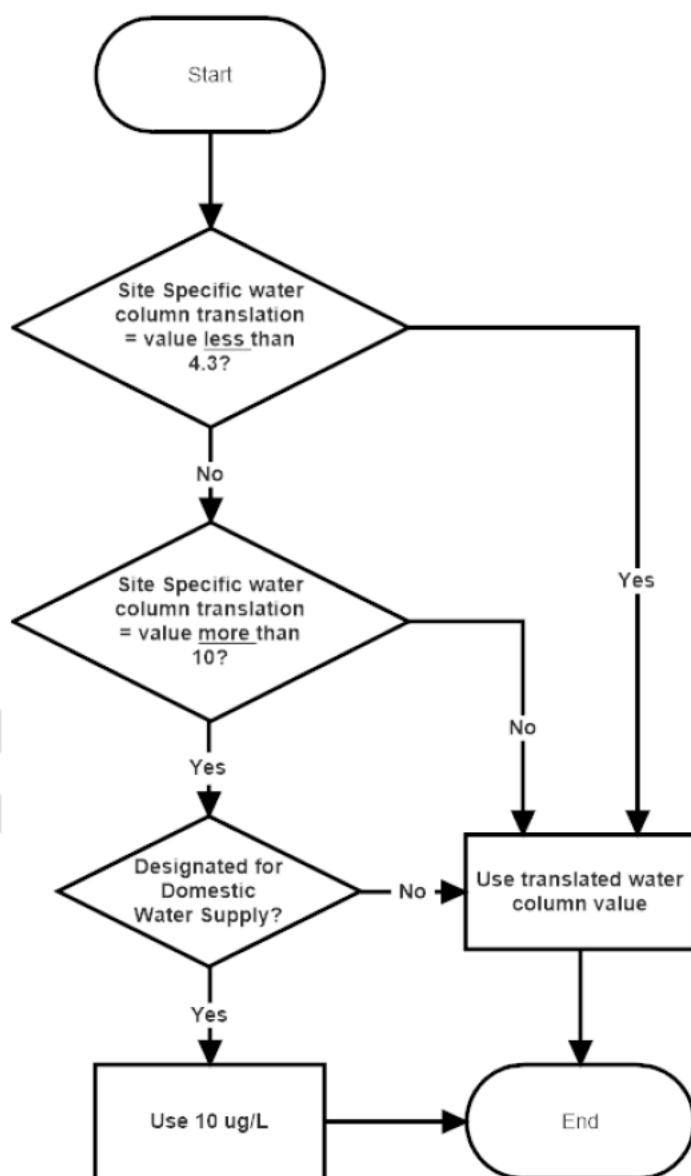
a) *Water column data available and fish tissue data available.*

- i) The DWS water column criterion element is met, the recreational use water column criterion element is met, and the fish tissue criterion element is met.
 - (1) Continued collection of water column data (not fish tissue data) can be used to demonstrate continued compliance with both the DWS and recreational use criterion elements.

-
- ii) The DWS water column criterion element is met, the recreational use water column criterion element is not met, and the fish tissue criterion element is met.
 - (1) Water body is ~~not~~ in compliance with the recreational use criterion element.
 - (2) Continued collection of water column data to demonstrate continuing compliance with DWS criterion element,
 - (3) **And** continued collection of fish tissue data can be used to demonstrate continued compliance with recreational criterion element, or a water column translation value can be developed using a site-specific BAF and continuing compliance with the recreational use element demonstrated using water column data.
 - iii) The DWS water column criterion element is met, the recreational use water column criterion element is not met, and the fish tissue criterion element is not met.
 - (1) Water body is not in compliance with the recreational use criterion element, the more restrictive use and applicable criteria.
 - (2) Continued collection of water column data to demonstrate continuing compliance with DWS criterion element.
 - iv) *The DWS water column criterion element is not met, the recreational use water column criterion element is not met, and the fish tissue criterion element is met.*
 - (1) *The water body is not in compliance with DWS criterion element,*
 - (2) *And continued collection of fish tissue data can be used to demonstrate continued compliance with recreational criterion element or collect fish tissue data to develop a water column translation value using a site-specific TL-BAF. The value cannot exceed the water column element for DWS.*
 - b) *Water column data available, fish tissue data not available.*
 - i) The DWS water column criterion element is met, and the recreational use water column criterion element is met.
 - (1) Continued collection of water column data (not fish tissue data) can be used to demonstrate continued compliance with both the DWS and recreational use criterion elements.
 - ii) The DWS water column criterion element is met, and the recreational use water column criterion element is not met.
 - (1) Water body is not in compliance with the recreational use criterion.
 - (2) Continued collection of water column data to demonstrate continuing compliance with DWS criterion element,
 - (3) **And** collection of fish tissue data can be used to determine compliance with the recreational criteria.
 - (a) If fish tissue criterion element is met, continued collection of fish tissue data can be used to demonstrate continued compliance with recreational use criterion element, or a water column translation value can be developed using a site-specific BAF and continuing compliance demonstrated using water column data.
 - (b) If fish tissue criterion element is not met; water body is not in compliance with the recreational use criterion element.
-

-
- iii) The DWS water column criterion element is not met, and the recreational use water column criterion element is not met.
 - (1) The water body is not in compliance with DWS and recreational criterion element,
 - (2) **And** collection of fish tissue data can be used to determine compliance with the recreational use criterion element.
 - (a) If fish tissue criterion element is met, continued collection of fish tissue data can be used to demonstrate continued compliance with recreational use criterion element, or a water column translation value can be developed using a site-specific BAF and continuing compliance demonstrated using water column data.
 - (b) If fish tissue criterion element is not met; water body is not in compliance with the recreational use criterion element.
- 3) Fishless recreational use waters.**
- a) *Fishless water column data available and downstream fish tissue data are available or can be collected.*
 - i) The water column criterion element is met, and the fish tissue criterion element is met.
 - (1) Continued collection of water column data (not fish tissue data) can be used to demonstrate continued compliance.
 - ii) The water column criterion element is not met, and the fish tissue criterion element is met.
 - (1) Continued collection of fish tissue data can be used to demonstrate continued compliance, or a water column translation value can be developed using a site-specific [TL](#)-BAF and continuing compliance demonstrated using water column data. (This scenario likely needs to be between the fishless water column and downstream fish and will not be spatially paired data.)
 - iii) The water column criterion element is met, and the fish tissue criterion element is not met.
 - (1) Water body is not in compliance with the recreational use criterion element.
 - iv) The water column criterion element is not met, and the fish tissue criterion element is not met.
 - (1) Water body is not in compliance with the recreational use criterion element.

Appendix C. Water Column Translation Criterion Decision Tree



Environmental Toxicology

Inorganic Arsenic Concentration in Fish Governed by Trophic Level and Size, not Water Concentration: Implications for Human Health Water Quality Criteria

Emily B. Morrison,^{a,*} Jason Pappani,^b Alan Prouty,^c Holly M. McChesney,^d and Paul D. Anderson^e

^aArcadis US, Hanover, Maryland

^bIdaho Department of Environmental Quality, Boise, Idaho, USA

^cJ.R. Simplot Company, Boise, Idaho, USA

^dArcadis US, Wexford, Pennsylvania

^eArcadis US, Chelmsford, Massachusetts

Abstract: In 2019, the Idaho Department of Environmental Quality implemented a paired surface water and fish tissue data collection program to derive a state-specific bioaccumulation factor (BAF) for inorganic arsenic (iAs) as part of the development of new human health water quality criteria (HHWQC). No statistically significant relationship was found between total arsenic (tAs) or iAs in surface water and fish tissue. Fish body weight was the only parameter with a statistically significant effect on iAs concentration in fish tissue. The ratio of iAs to tAs in fish tissue declined significantly with both increasing trophic level and increasing body weight. The decrease in iAs concentration in fish tissue with increasing size and trophic level as well as the decrease in the proportion of tAs that is iAs with increasing trophic level are likely the result of metabolic transformation of iAs to organic As by organisms in each level of the aquatic food web. Although the linear regression-based BAF using the Idaho paired fish and water data best predicted observed iAs fish tissue concentrations compared to several alternative BAFs, it was not statistically significant ($p < 0.05$) and was a poor predictor ($R^2 = 0.01$) of iAs concentrations in fish tissue. These results illustrate that iAs, and possibly other metals, in the natural environment do not conform with commonly used bioaccumulation models and the paradigm used by the US Environmental Protection Agency for determining HHWQC. These results indicate that modifications to the paradigm are necessary, such as a fish tissue criterion as Idaho has proposed, to assure that public health is protected. *Environ Toxicol Chem* 2023;42:1542–1552. © 2023 SETAC

Keywords: Bioaccumulation; Water quality criteria; Metals

INTRODUCTION

Metals transferred through aquatic food webs and to fish consumed by humans can pose a risk to human health. Arsenic is a naturally occurring metalloid (Chen & Folt, 2000; Mandal & Suzuki, 2002; Smedley & Kinniburgh, 2002; Tanner et al., 2000) whose toxicity depends on its concentration and speciation. Arsenic species include both inorganic (e.g., arsenite [AsIII] and arsenate [AsV]) and organic species (e.g., methylated species, arsenobetaine, arsenolipids, and arsenosugars). Inorganic species are generally more toxic than organic species (Agency for Toxic Substances and Disease Registry, 2007; Cubadda

et al., 2017; Ng, 2005; Rahman et al., 2012) and assumed to pose the greatest risk to human health; they are, therefore, the species of arsenic regulated by human health water quality criteria (HHWQC).

Human health water quality criteria are required as part of the Clean Water Act. Idaho's current inorganic arsenic (iAs) HHWQC of 10 µg/L is based on the Safe Drinking Water Act maximum contaminant level (MCL), which is also consistent with World Health Organization (2017) drinking water guidelines. The US Environmental Protection Agency (USEPA) has recommended national HHWQC for arsenic of 0.14 µg/L and 0.018 µg/L for consumption of organisms only and for consumption of water and organisms, respectively (USEPA, 2002). Background concentrations of iAs in Idaho's waters range from less than the detection limit of 0.04–19.8 µg/L, with a median of 0.83 µg/L (Idaho Department of Environmental Quality [IDEQ], 2020). Consequently, iAs

This article includes online-only Supporting Information.

* Address correspondence to emily.morrison@arcadis.com

Published online 21 April 2023 in Wiley Online Library

(wileyonlinelibrary.com).

DOI: 10.1002/etc.5636

concentrations in the majority of Idaho waters exceed USEPA national HHWQC, but concentrations in virtually all waters meet Idaho's current HHWQC. Litigation over the use of an MCL as the HHWQC resulted in an agreement with the USEPA to initiate a new iAs HHWQC rulemaking process (Opalski, 2016). That process is currently underway and is the catalyst for the data collection and evaluation effort described in this paper.

For compounds assumed to cause cancer, like iAs, establishment of HHWQC requires several inputs, including fish consumption rate, bioaccumulation factor (BAF), body weight, cancer slope factor, and allowable risk level. Idaho water quality standards (WQS) define those inputs (Idaho Administrative Procedures Act, 2020). The BAF is used to predict fish tissue concentration from water concentration and represents the fundamental conceptual basis underlying the use of a BAF in an HHWQC: that a direct relationship exists between water and fish tissue concentrations (see Supporting Information for detailed discussion of BAF development).

Idaho WQS and USEPA guidance allow for the derivation of Idaho-specific inputs, including an Idaho-specific BAF, when the inputs used in USEPA national HHWQC may not apply to Idaho (Idaho Administrative Procedures Act, 2020; USEPA, 2000a). The USEPA national arsenic HHWQC uses a bioconcentration factor (BCF) of 44 L/kg. That BCF is derived by weighting a finfish BCF of 1 L/kg and a shellfish BCF of 350 L/kg by the proportion of total estuarine and freshwater fish consumption assumed to be comprised of finfish (5.7 g/person/day) and shellfish (0.8 g/person/day; USEPA, 1980). Given that finfish but not shellfish are consumed from Idaho waters (IDEQ, 2015), a BCF closer to 1 L/kg, representative of finfish arsenic accumulation, rather than 44 L/kg, which includes consumption of shellfish, may be more appropriate for Idaho as well as other states with limited consumption of native shellfish. Several studies published since the USEPA derived the BCF of 44 L/kg report no relationship between total arsenic (tAs) in surface water and fish tissue in natural environments, with tAs concentrations in fish tissue remaining relatively constant across a wide range of surface water concentrations (Skinner, 1985; Williams et al., 2006).

In freshwater systems, arsenic concentrations decrease with increasing trophic level (TL) in the food web, referred to as *biodilution* (or *biodimution*; Chen & Folt, 2000; Chen et al., 2008; Cheng et al., 2013; Chetalat et al., 2019; Dovick et al., 2015; Lopez et al., 2016; Maeda et al., 1990; USEPA, 2003a). This pattern of biodilution with increasing TL is confirmed by stable isotope studies that more precisely establish the TLs of organisms in the aquatic food web (Otter et al., 2012; Revenga et al., 2012).

Internal bioregulation appears to convert the more toxic inorganic species of arsenic (e.g., AsIII and AsV) to nontoxic organic species (e.g., arsenobetaine and methylated forms of arsenic; Rahman et al., 2012; USEPA, 2003a), though increasing direct ingestion of organic arsenic species by higher-TL organisms may also contribute to observed biodilution of iAs (Maher et al., 2011). Organic forms of arsenic were 58%–100% of the tAs measured in tissues (including muscle, liver, and gill)

in rainbow trout (Ciardullo et al., 2008); tilapia (Pei et al., 2019); carp (Cui et al., 2021); carp, eel, mullet, and chub (Ciardullo et al., 2010); and creole perch, rainbow trout, and brown trout (Juncos et al., 2019). After dietary exposure to iAs in the laboratory, 90% of tAs concentrations in muscle, liver, and gill tissues in tilapia were comprised of organic species; but only 30%–80% of tAs in the gastrointestinal tract was comprised of organic arsenic species (Pei et al., 2019), suggesting that biotransformation of iAs occurred after ingestion. In addition, proportions of arsenobetaine increased with prolonged exposure to iAs, suggesting that fish had an adaptive response by increasing iAs biotransformation into the nontoxic arsenic species (Cui et al., 2021).

To better understand accumulation of arsenic by fish in Idaho waters, in 2019 the IDEQ developed and implemented a paired surface water and fish tissue data collection program for the purposes of deriving an Idaho-specific BAF.

A specific focus of the collection program was developing information on concentrations of iAs, the species of arsenic assumed to be most toxic to humans. The majority of data available in the literature are for tAs; however, it is iAs in surface water and fish that is regulated by the USEPA's HHWQC and about which limited bioaccumulation data are available in the literature. We are not aware of a comparable geographically large-scale collection of paired iAs in fish tissue and surface water data. This paper evaluates the relationship between concentrations of arsenic in surface water and fish tissue in Idaho, identifies factors affecting the concentrations of iAs in fish tissue, and discusses the significance of these findings on the HHWQC development methodology used by the USEPA for iAs.

METHODS

Field data collection

Between August 14, 2019, and October 17, 2019, the IDEQ collected paired surface water and fish tissue samples and analyzed those for iAs and tAs at 24 randomly selected river reach locations across the state (IDEQ, 2020; Figure 1). Samples were taken in major river basins including the Clearwater, Lower Bear, Spokane, Salmon, Middle Snake, and Upper Snake river basins.

At each sample location, a river reach was defined as 40 times the general wetted width of the reach, with a minimum reach length of 150 m and maximum reach length of 4000 m. One surface water and up to three fish samples were collected at each of the 24 sample locations. To balance resource availability and the inclusion of representative samples from throughout the state of Idaho, monitoring was focused on single, reconnaissance-level site visits, rather than analysis of individual fish and multiple fish species and sizes from only a few sites.

Field duplicate samples were collected at two locations for surface water and three locations for fish tissue. Fish duplicate samples were tissue from separate fish samples collected at the same location and time and of the same species, rather than a single tissue sample that was split into parent and

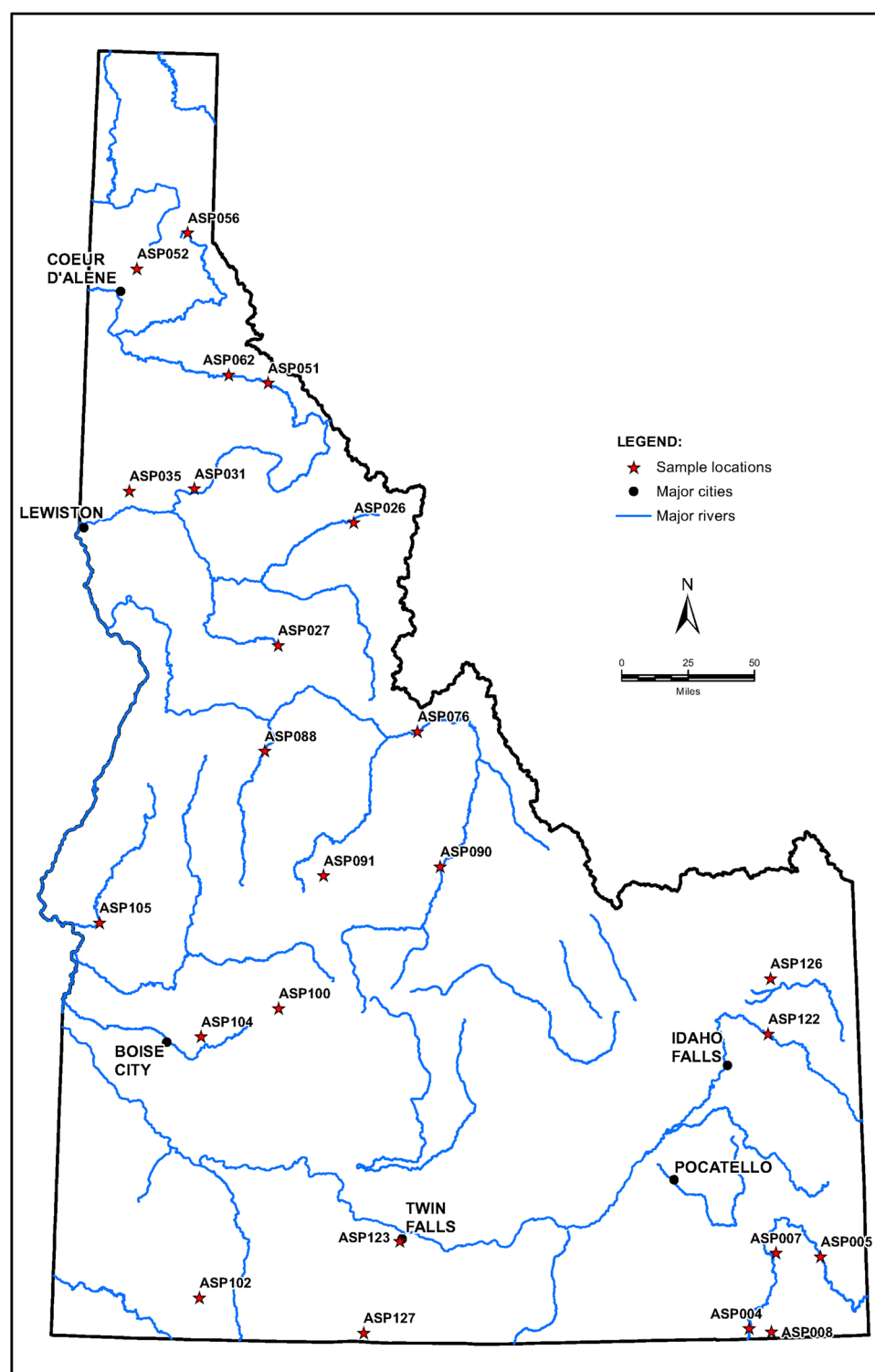


FIGURE 1: Fish tissue and surface water sampling locations in Idaho (2019).

duplicate samples after collection. Fish duplicates were therefore treated as independent samples in this analysis.

Water samples were collected and composited from three transects within each reach. The three transects were located at the top of the reach, mid-reach, and the bottom of the reach. Each transect was sampled at one-quarter, one-half, and three-quarters of the stream width, resulting in three subsamples

per transect and a total of nine subsamples per reach. The nine subsamples were composited in a high-density polyethylene sample container. Samples were analyzed for tAs and iAs.

Each of the 24 locations was electrofished throughout the reach. If electrofishing within the predetermined reach did not yield the goal of five fish per species, electrofishing continued downstream until the boat takeout or until the target of

five fish per species was captured. Five individuals of the same species were collected. Following USEPA compositing guidance (USEPA, 2000b) to ensure that individuals in a composite were of similar size, the smallest individual in a composite sample was no less than 75% of the total length of the largest individual. At many of the river reach locations it was not possible to collect five individual fish of two species; 27 of the 48 fish samples were comprised of fewer than five individual fish. At three locations, only a single species could be collected; and at one location, three species were collected. A total of 24 surface water and 48 fish tissue samples were collected (see Supporting Information, Tables S2 and S3, for raw data).

Sampled fish were identified to species, where possible. Some catfish and sculpin fish were identified to genus only. Fish were then measured for length and weight.

Whole fish were dispatched, rinsed with ambient water, placed in a zip-top bag, and frozen on dry ice within 24 h of collection. Once received by the contract laboratory, individual fish were processed to extract muscle tissue by removing a 10-g plug of tissue from the thickest section of the fish muscle tissue. A tissue sample was comprised of the composited, homogenized sample from all fish of the same species at each site.

Fish species sampled included common game fish (trout, bass, catfish, and whitefish) as well as other “nongame” species that can be consumed, such as suckers. When setting HHWQC for the protection of human health, Idaho established a fish consumption rate based on a fish consumption survey that included all Idaho fish, not just game fish (IDEQ, 2015; Northwest Research Group, 2015). A fish tissue-based water quality criterion would apply to all fish species, regardless of likelihood of consumption. Therefore, although the sample collection targeted commonly consumed size and species of game fish, in the absence of suitable game fish species, other nongame species, or fish of sizes that are not commonly consumed, were sampled.

Tissue and water sample chemistry analysis methods

Water and fish tissue samples were analyzed for total recoverable arsenic by inductively coupled plasma-mass spectrometry following USEPA Method 1638 (USEPA, 1996a). Fish tissue samples were digested via modified USEPA Method 3050B (USEPA, 1996b) with a mix of concentrated nitric acid, hydrochloric acid, and hydrogen peroxide. A known mass of each tissue sample was placed into a polypropylene vial and extracted with concentrated nitric acid, and hydrogen peroxide was added in stages while being heated at 95 °C for 5 h. The resulting extracts were analyzed for arsenic species with ion chromatography inductively coupled plasma collision reaction cell mass spectrometry (IC-ICP-CRC-MS). Filtered (0.45 µm) water samples were digested in an oven in a closed vessel via EPA Method 1638 (USEPA, 1996a) with nitric and hydrochloric acids. Arsenic was analyzed using inductively coupled plasma

triple quadrupole mass spectrometry, and arsenic species analysis was conducted using IC-ICP-CRC-MS. All tissue and water analyses were performed by Brooks Applied Labs. Analytical methods are detailed in the arsenic monitoring quality assurance project plan (IDEQ, 2019). Laboratory quality assurance included method blanks, laboratory control standards, matrix duplicates, and matrix spikes in accordance with the Brooks Applied Labs Comprehensive Quality Assurance Plan (Brooks Applied Labs, 2018).

Data analysis methods

Surface water duplicates showed little to no variation (<10%) and were averaged for use in the analyses. As described above, fish duplicate samples were separate tissue samples collected from different individuals of the same species at the same location and time and treated as independent samples in this analysis. Sample results reported as less than the maximum detection limit (MDL) were assigned the MDL for all analyses. Sample-specific BAFs were calculated as a ratio (referred to as *ratio BAFs* hereafter) between paired composite fish and water concentrations at a sampling location (Supporting Information, Table S5, and additional BAF discussion in the Supporting Information).

Fish species were assigned to TLs following the methods used by the USEPA (USEPA, 2014, 2016a), including information from its Rapid Bioassessment Protocol (USEPA, 1999), and are presented in Supporting Information, Table S1. Bridgelip sucker is the only species assigned to TL-2 (Dauble, 1980); they are predominantly herbivorous fish. Primarily insectivorous or omnivorous fish were assigned to TL-3. Fish feeding on upper-TL invertebrates or other fish were assigned to TL-4.

Linear regression analyses were used to examine the effect of surface water iAs and tAs concentrations on iAs and tAs in fish tissue, the relationship between iAs in surface water and the iAs BAF, fish body weight on tissue iAs concentrations, the effect of fish weight on the ratio of iAs to tAs in tissue, and the effect of TL on the relationship between iAs concentrations in tissue and surface water. An analysis of variance (ANOVA) was used to examine the effects of TL on the ratio of iAs to tAs in tissue.

A general linear model with Type III sum of squares was used to examine if any parameters collected by the IDEQ or that could be inferred based on life histories have a statistically significant influence on the concentration of iAs in fish tissue. Parameters included in the statistical model consisted of TL (TL-2, TL-3, TL-4), river basin from which samples were collected, fish species, average fish composite sample weight, concentration of iAs in water, concentration of tAs in water, and concentration of tAs in fish tissue.

Data were examined for normality and homogeneity of variance. To meet statistical model assumptions, the iAs to tAs ratio variable was logit-transformed (Warton & Hui, 2011), and all other variables were natural log-transformed for statistical analyses. The general linear model, ANOVA, and linear regression analyses described above were conducted in Systat, Ver 13 (Systat, 2017).

As noted above, the primary goal of the 2019 data collection effort was to collect data to derive an Idaho-specific BAF for iAs; BAFs are defined as the relationship of the concentration of a compound in fish to the concentration in water (USEPA, 2003b). The following Idaho-specific BAFs were developed using the 2019 Idaho-specific data: (1) geometric mean of all ratio BAFs, (2) TL-weighted BAF based on the geometric mean of the TL ratio BAFs, (3) regression equation of iAs in surface water and fish, and (4) the TL-weighted regression equation of iAs in surface water and fish (see Supporting Information for additional details on how these alternate BAFs are calculated).

The relative performance of the Idaho-specific BAFs at predicting iAs concentrations in fish tissue from colocated iAs water samples was evaluated using the Akaike information criterion statistic corrected for small sample size (AIC_c). In addition, the BAFs of 44 L/kg for all freshwater and estuarine fish and 1 L/kg for finfish used by the USEPA to derive the national HHWQC for iAs (USEPA, 1980) were included to compare their relative ability to predict iAs concentrations in fish tissue from colocated iAs water samples collected in Idaho. To allow all models to be compared via the AIC_c , regression models developed from natural log-transformed data were evaluated as power functions on the untransformed data (power functions are equivalent to linear regressions on natural log-transformed data). In addition, non-regression-based BAFs and models not derived directly from the Idaho data were evaluated by comparing the colocated fish tissue and surface water data to predicted results derived from those models. Log-likelihood values were obtained based on the fit of each model to the colocated fish tissue and surface water data. The AIC_c values were calculated from the resulting log-likelihood values and the number of model parameters and used to calculate the relative probability (AIC_c weight) that the model best represented the data (Burnham et al., 2011). Deviance, a measure of goodness of fit, was also calculated for each model. Models with lower AIC_c values and higher AIC_c weights are better predictors of the data compared to the other models evaluated. All analyses were performed using the $AIC_{cmodavg}$ package in program R (2021).

RESULTS

Fish size

A total of 171 individual fish, representing 14 species and three TLs were collected from the 24 sampling locations, resulting in 48 composite samples (Supporting Information, Table S1). Fish length ranged from 60 mm to 630 mm, with an

arithmetic mean of 220 mm (Supporting Information, Table S1). Weight ranged from 2 g to 3340 g, with an arithmetic mean of 231 g (Supporting Information, Table S1). Sculpin spp., dace spp., and reidside shiners were the smallest species (arithmetic mean weight <15 g). Catfish sp. and common carp were the largest species (arithmetic mean weight >1500 g). All other species had arithmetic mean weights between 30 and 375 g. The full fish species, length, weight, and arsenic fish tissue and surface water concentration data set is presented in Supporting Information, Tables S2–S4.

Concentration of arsenic in fish tissue

The tAs concentration in fish tissue ranged from 0.9 to 583 $\mu\text{g/kg}$, with an arithmetic mean of 75 $\mu\text{g/kg}$ (Table 1; Supporting Information, S1), and, consistent with trends reported in the literature, tends to decrease with increasing TL, though the differences are not statistically significant ($df=2.45$, $F=0.25$, $p=0.78$). Fish in TL-4 have the lowest mean tAs concentration (55 $\mu\text{g/kg}$), TL-3 fish have the highest (81 $\mu\text{g/kg}$), and TL-2 fish are intermediate (75 $\mu\text{g/kg}$; Supporting Information, Table S1).

Concentrations of iAs in fish tissue are substantially lower than tAs concentrations, ranging from 0.2 to 10 $\mu\text{g/kg}$, with an arithmetic mean of 1.8 $\mu\text{g/kg}$ (Table 1). Inorganic arsenic tissue concentration exhibits a statistically significant decline ($df=2.45$, $F=7.36$, $p=0.002$, Tukey's post hoc test) with increasing TL, from 5.57 $\mu\text{g/kg}$ in TL-2 to 2.14 $\mu\text{g/kg}$ in TL-3 to 0.38 $\mu\text{g/kg}$ in TL-4 (Supporting Information, Table S1).

Concentration of arsenic in surface water

Concentrations of tAs in surface water range from 0.07 to 7.3 $\mu\text{g/L}$, with an arithmetic mean of 1.9 $\mu\text{g/L}$ (Table 1). Concentrations of iAs in surface water range from 0.04 to 8.1 $\mu\text{g/L}$, with an arithmetic mean of 1.7 $\mu\text{g/L}$ (Table 1), indicating that iAs as a proportion of tAs in surface water is high, and thus organic As in surface water is low.

Relationship between arsenic in surface water and fish tissue

The relationships between the concentration of tAs in surface water and fish tissue ($p=0.30$; Figure 2A) or between iAs in surface water and fish tissue ($p=0.56$; Figure 2B and

TABLE 1: Summary statistics for fish tissue and surface water arsenic concentrations

Metric	<i>n</i>	Frequency of detection (%)	Mean	Standard deviation	Minimum	Maximum
Surface water						
Total arsenic ($\mu\text{g/L}$)	24	100	1.9	2.0	0.07	7.3
Inorganic arsenic ($\mu\text{g/L}$)	24	96	1.7	1.9	0.04	8.1
Fish tissue						
Total arsenic ($\mu\text{g/kg}$)	48	96	75	97	0.9	583
Inorganic arsenic ($\mu\text{g/kg}$)	48	73	1.8	2.7	0.2	10

Three surface water duplicate samples were averaged with their parent samples.

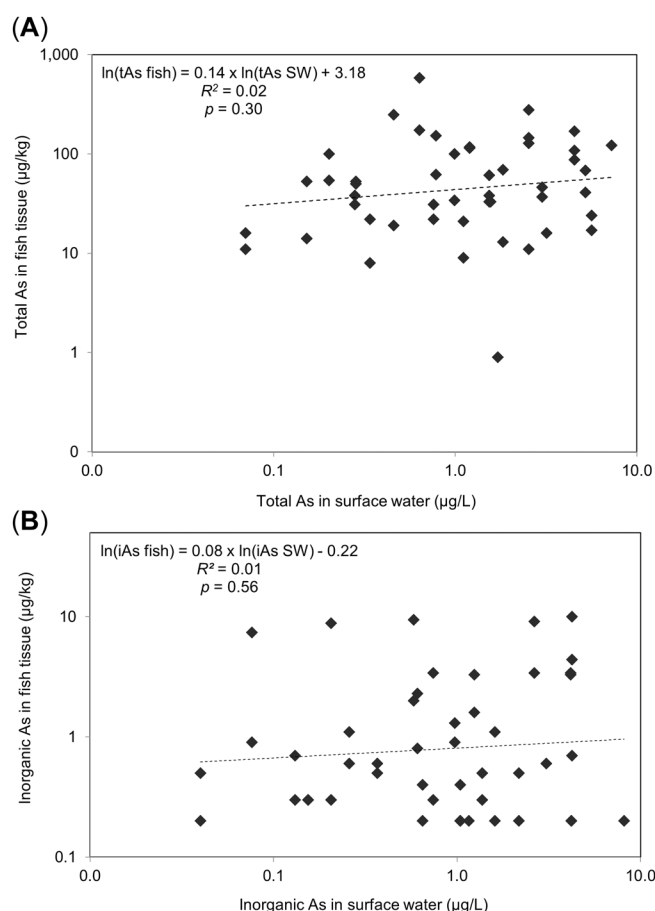


FIGURE 2: (A) Relationship between total arsenic in surface water and fish tissue. (B) Relationship between inorganic arsenic in surface water and fish tissue. tAs = total arsenic; SW = surface water; iAs = inorganic arsenic.

Table 2) are not statistically significant. The concentration of arsenic in water explained little of the variation in fish tissue concentration (2% and 1% for tAs and iAs, respectively; Figure 2). Statistically significant relationships ($p < 0.05$) between iAs concentrations in fish tissue and water are also absent for individual species with five or more paired data points, except for the sculpin species, with no consistent trends (Table 2). The concentration of iAs in fish tissue increases with increasing iAs water concentration for cutthroat trout and northern pikeminnow and decreases with increasing

water concentration for brown trout and rainbow trout. Sculpin species show a statistically significant increase in tissue iAs concentration with increasing iAs in surface water. Statistically significant relationships are absent when fish are grouped by TL ($p > 0.05$; Table 2). With increasing iAs water concentration, iAs tissue concentrations increased in TL-2 fish, changed little in TL-3 fish, and decreased slightly in TL-4 fish (Table 2; Supporting Information, Figure S1).

Multivariate analysis and effect of weight

Arithmetic mean weight of composite samples is the only parameter with a statistically significant effect on the concentration of iAs in fish tissue (Table 3). None of the other parameters included in the analysis (river basin, species, TL, tAs in fish tissue, and iAs and tAs in surface water) had a statistically significant effect on the iAs concentration in fish tissue (Table 3). Surface water iAs and tAs concentrations were significantly positively correlated (Pearson's $r = 0.98$, $p < 0.001$); however, when the analysis was rerun without tAs in surface water, weight was still the only significant factor.

When regression analysis is used to investigate the effect of weight on iAs in fish tissue, the relationship between composite fish body weight and iAs in tissue is statistically significant ($p = 0.01$), although the regression equation explains only 14% of the variation (Figure 3). Except for bridgelip sucker, the only primarily herbivorous and TL-2 species in the data set, a threshold seems to be present in the relationship between weight and iAs tissue concentration. Fish weighing < 100 g have a wide range of iAs tissue concentrations, from 0.2 to 9.4 µg/kg. Above 100 g, most fish have iAs tissue concentrations of ≤ 1 µg/kg, and all such fish have iAs concentrations of ≤ 2 µg/kg (Figure 3).

When fish are grouped by TL, trends with weight are also apparent. The concentration of iAs in TL-2 fish tissue increases with increasing body weight ($p = 0.63$; Supporting Information, Figure S2a), although this relationship is not significant, likely because of the low sample size. The iAs concentrations in TL-3 ($p = 0.01$, $R^2 = 0.20$; Supporting Information, Figure S2b) and TL-4 ($p = 0.69$, $R^2 = 0.02$; Supporting Information, Figure S2c) fish tissue decrease with increasing body weight, but only the trend in TL-3 fish is statistically significant.

TABLE 2: Summary of inorganic arsenic surface water to fish tissue regression results for all species, individual species, and trophic levels

Species or group	Sample size	Regression equation	R^2	p
All species	48	$\ln(iAs \text{ Fish}) = 0.08 \times \ln(iAs \text{ SW}) - 0.22$	0.01	0.56
Brown trout	5	$\ln(iAs \text{ Fish}) = -0.49 \times \ln(iAs \text{ SW}) - 0.81$	0.57	0.08
Cutthroat trout	9	$\ln(iAs \text{ Fish}) = 0.08 \times \ln(iAs \text{ SW}) - 0.08$	0.008	0.83
Northern pikeminnow	5	$\ln(iAs \text{ Fish}) = 0.08 \times \ln(iAs \text{ SW}) - 1.01$	0.02	0.82
Rainbow trout	6	$\ln(iAs \text{ Fish}) = -0.20 \times \ln(iAs \text{ SW}) + 0.25$	0.04	0.71
Sculpin sp.	7	$\ln(iAs \text{ Fish}) = 0.61 \times \ln(iAs \text{ SW}) + 0.92$	0.78	0.01
Trophic level 2	3	$\ln(iAs \text{ Fish}) = 0.55 \times \ln(iAs \text{ SW}) + 1.11$	0.69	0.38
Trophic level 3	36	$\ln(iAs \text{ Fish}) = 0.20 \times \ln(iAs \text{ SW}) - 0.02$	0.05	0.20
Trophic level 4	9	$\ln(iAs \text{ Fish}) = -0.46 \times \ln(iAs \text{ SW}) - 0.85$	0.23	0.20

Nondetects were set equal to the detection limit. Bolded value indicates significant relationship at $p < 0.05$.

iAs = inorganic arsenic (µg/kg); Ln = natural log; SW = surface water (µg/L).

TABLE 3: Results of general linear model

Parameter	Type III sum of squares	F ratio	p
Basin	0.577	0.67	0.65
Species	1.3	0.64	0.79
Trophic level	0.005	0.02	0.98
Average fish sample weight	1.3	7.75	0.01
Fish tissue total arsenic	0.105	0.61	0.44
Surface water total arsenic	0.27	1.57	0.22
Surface water inorganic arsenic	0.408	2.37	0.14
Error	4.0		

The average fish sample weight is the average weight of the fish comprising each composite sample. Bolded parameters are significant at $p < 0.05$.

Inorganic arsenic to total arsenic ratio in fish tissue

Inorganic arsenic was a small proportion of the tAs in Idaho fish tissue (mean percent iAs = 3.48%, range = 0.16%–22.2%). The TL affects the proportion of iAs in fish tissue. The average iAs to tAs ratio declines with increasing TL from 0.073 in TL-2 to 0.038 in TL-3 to 0.008 in TL-4 (Supporting Information, Table S1). The difference in iAs to tAs ratios is statistically significant between TL-4 and TL-2 and between TL-4 and TL-3 (Figure 4; $df = 2.45$, $F = 6.82$, $p = 0.003$, Tukey's post hoc test) but not between TL-2 and TL-3.

The iAs to tAs ratio also shows a statistically significant decrease with increasing body weight ($p < 0.001$, $R^2 = 0.09$; Supporting Information, Figure S3). However, the trend is not consistent between TLs. The ratio changes little with increasing body weight in TL-2 ($p = 0.42$, $R^2 = 0.63$) and TL-4 ($p = 0.69$, $R^2 = 0.02$) but shows a statistically significant decline with weight in TL-3 ($p = 0.008$, $R^2 = 0.20$).

Predictive ability of alternate BAFs

The 48 iAs ratio BAFs range from 0.02 to 97 (see Supporting Information, Table S5) and for some species at some locations can be as much 80-fold higher or 40-fold lower than the

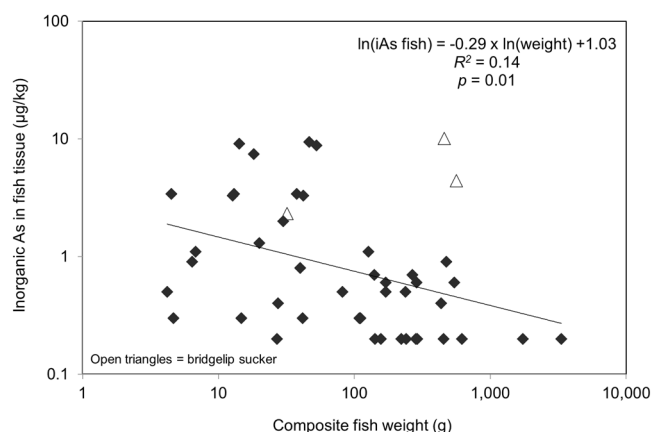


FIGURE 3: Inorganic arsenic in fish tissue by composite fish sample weight. Open triangles represent bridgellip sucker samples, and closed diamonds represent all other samples. iAs = inorganic arsenic.

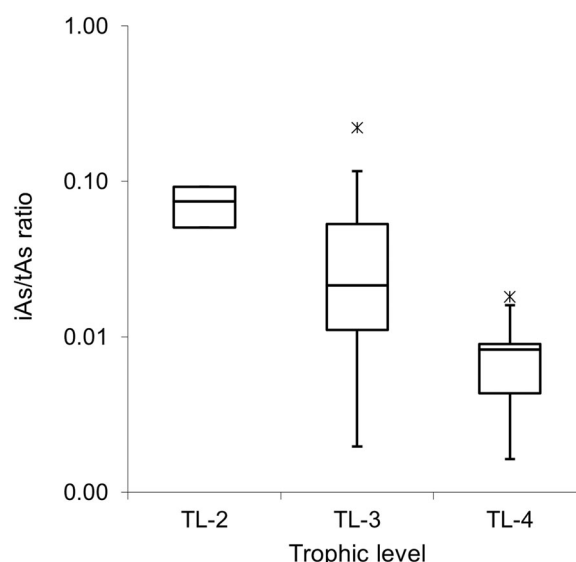


FIGURE 4: Inorganic to total arsenic ratios across trophic levels. Different letters indicate significant differences among groups. iAs = inorganic arsenic; tAs = total arsenic; TL = trophic level.

geometric mean ratio BAF of 1.03 L/kg. Ratio BAFs may vary substantially between species at the same sampling location. For example, at Mores Creek, rainbow trout have a ratio BAF of 0.17 L/kg, while bridgellip suckers have ratio BAFs of 2.4 and 1.0 L/kg (see Supporting Information, Table S5). Ratio BAFs also vary for a single species across sampling locations. Rainbow trout ratio BAFs decrease from 97 L/kg to 0.17 L/kg as iAs water concentrations increase from 0.076 µg/L to 4.22 µg/L across six sampling locations (see Supporting Information, Table S5). When deriving HHWQC, the USEPA assumes that the BAF is identical across all water concentrations (i.e., the relationship between fish tissue and water is constant). Our data show that instead of a constant relationship, ratio BAFs have a statistically significant decline with increasing iAs in surface water ($p < 0.001$, $R^2 = 0.49$; Supporting Information, Figure S4), a trend inconsistent with the USEPA's fundamental assumption about BAFs (see additional discussion of this topic in the Supporting Information).

Comparison of the ability of the alternate BAFs to predict measured concentrations of iAs in fish tissue using the AIC_c statistic indicates that the regression-based BAF on all data combined was the best predictor of observed Idaho fish tissue concentrations (Table 4). However, although this BAF was the best model compared to the other alternatives examined, it was a poor predictor of fish tissue iAs concentration from surface water ($R^2 = 0.01$, $p = 0.56$; Table 2 and Figure 2B). The extremely large HHWQC using the Idaho-specific data (Table 4) is the result of the lack of a relationship between iAs in surface water and iAs in fish. The TL-weighted regression was ranked lower than the BAF regression using all data combined because the AIC method penalizes models that contain more parameters. The BAF of 44 L/kg used to derive the USEPA's national HHWQC is the worst predictor compared to the other models (Table 4). The greater predictive ability of the regression-based BAFs compared to the other BAFs evaluated

TABLE 4: Alternate bioaccumulation factors are presented along with their respective Akaike information criterion (AIC_c), relative likelihood, AIC_c weight, and deviance

BAF description	BAF	AIC_c	Relative likelihood	AIC_c weight	Deviance	Associated iAs HHWQC ($\mu\text{g/L}$)
Regression equation BAF based on Idaho data set	$(\text{iAs Fish}) = 0.806 \times (\text{iAs SW})^{0.082}$	234.3	1	0.97	339.1	^a
TL-weighted regression equation BAF based on Idaho data set	$(\text{iAs Fish}) = 0.36 \times [3.02 \times (\text{iAs SW}_{\text{TL2}})^{0.546}] + 0.40 \times [0.980 \times (\text{iAs SW}_{\text{TL3}})^{0.203}] + 0.24 \times [0.427 \times (\text{iAs SW}_{\text{TL4}})^{-0.459}]$	235.3	0.011	0.01	345.7	31.7
Finfish iAs BAF assumed by current national AWQC	1 L/kg	243.4	0.010	0.01	428.9	8
Geometric mean of all Idaho ratio BAFs ^b	1.12 L/kg	246.1	0.002	0.00	453.1	7.14
TL-weighted BAF based on geometric mean of TL ratio Idaho ^b BAFs	1.87 L/kg	271.2	0.000	0.00	764.6	4.27
iAs BAF in current national AWQC	44 L/kg	578.5	0.000	0.00	461,445	0.18

^aAs the slope approaches zero (indicating no relationship between iAs concentration in surface water and fish tissue), the resulting HHWQC approaches infinity.

^bThe geometric BAFs reported in the present study and used in the AIC_c evaluation are those calculated by the Idaho Department of Environmental Quality (IDEQ) during the iAs HHWQC rulemaking process. The IDEQ calculated the geometric means by first averaging the fish duplicate samples and then calculating the geometric BAFs. That procedure is slightly different from the one used in the present study, where all fish duplicate samples were treated as independent, resulting in slightly different geometric BAFs (all Idaho geometric BAFs = 1.03 L/kg and TL-weighted geometric BAFs = 1.39 L/kg). The associated iAs HHWQC values derived using exposure and toxicity assumptions adopted by Idaho using each BAF are also presented. The TL-weighted BAF = $(\text{BAF}_{\text{TL2}} \times \text{Fraction FCR}_{\text{TL2}}) + (\text{BAF}_{\text{TL3}} \times \text{Fraction FCR}_{\text{TL3}}) + (\text{BAF}_{\text{TL4}} \times \text{Fraction FCR}_{\text{TL4}})$. To allow all models to be compared via AIC_c , the two regression models developed from natural log-transformed data were evaluated as power functions on the untransformed data (power functions are equivalent to linear regressions on natural log-transformed data). The geometric mean of all Idaho ratio BAFs and the TL-weighted BAF based on the geometric mean of the TL ratio Idaho BAFs were used as part of the Idaho HHWQC rulemaking process. Inorganic arsenic fish concentration units are micrograms per kilogram, and surface water iAs concentration units are micrograms per liter. BAF = bioaccumulation factor; FCR = fish consumption rate; iAs = inorganic arsenic; HHWQC = human health water quality criteria; SW = surface water; TL = trophic level; AWQC = ambient water quality criteria.

in the present study is expected given that the outcome of regression analysis is the relationship that best fits the observed data. That lack of predictive ability of the national BAF (44 L/kg) is also not surprising given that it is not based on Idaho-specific data, though the finfish-only national BAF (1 L/kg), also not based on Idaho-specific data, is a better predictor than the Idaho-specific geometric mean BAF (Table 4). The lack of predictive ability of the Idaho-specific ratio BAFs is likely related to the large amount of variation between ratio BAFs across locations as well as within and between species. Even though the regression-based Idaho-specific BAF best fit the Idaho data compared to the other models tested, it has little predictive utility in describing the relationship between iAs in surface water and fish tissue.

DISCUSSION

Bioaccumulation factors are a critical parameter in the derivation of HHWQC because they link fish tissue concentrations with water column concentrations of substances regulated by an HHWQC. The fundamental conceptual basis underlying the use of a BAF in an HHWQC is the existence of a direct relationship between water and fish tissue concentrations. Because BAFs can be affected by site-specific conditions (USEPA, 2003b), the primary purpose of the state-wide collection effort undertaken by Idaho in 2019 was to collect a robust paired data set to derive an Idaho-specific BAF for iAs. A key finding from that data collection effort is the absence of a statistically significant relationship between iAs (or tAs) in fish tissue and surface water in Idaho. The lack of a relationship between arsenic in the water column and fish tissue is consistent with previously published data (Skinner, 1985; Williams et al., 2006), although those data were primarily for tAs. The data collected by Idaho in 2019 included speciation of arsenic to quantify the concentration of the more toxic iAs species in tissue and water and, thus, represent an important extension of our understanding of the bioaccumulation patterns of arsenic, and particularly iAs, in natural environments.

Previous studies (Chen & Folt, 2000; Chen et al., 2008; Cheng et al., 2013; Chetalat et al., 2019; Dovick et al., 2015; Lopez et al., 2016; Maeda et al., 1990) have reported that concentrations of tAs in fish tissue and other aquatic biota appear to be related to TL and to decrease with increasing TL. The decline in iAs concentration with increasing TL in Idaho fish parallels the decline in tAs concentration reported in these studies, but to our knowledge, this is the first large-scale field study to report a similar decline for iAs, the arsenic species regulated by HHWQC.

Inorganic arsenic concentrations in fish tissue were affected by other parameters likely related to TL. For example, fish body weight can serve as a surrogate for TL for many species (Behnke, 1992; Sundbom et al., 2003), with small fish representing lower TLs and large fish higher TLs. Fish weight is the only variable in the multivariate analysis that had a statistically significant effect on the concentration of iAs in fish tissue, with larger fish having lower concentrations of iAs than smaller fish,

consistent with findings from other studies on tAs (Liao et al., 2003). Small fish of the majority of species included in the data set likely represent a lower TL feeding on algae and small, lower-TL invertebrates, even though as adults they are primarily insectivorous, feeding on upper-TL invertebrates (e.g., shiners, sculpin, dace, cutthroat trout; Becker, 1983; Gray & Dauble, 2001; Liknes & Graham, 1988; Morrow, 1980), or are piscivorous, feeding on fish (e.g., bass, most trout species; Behnke, 1992; Scott & Crossman, 1973). Of all species included in the data set, the only species that does not follow this pattern is the bridgelip sucker; adult bridgelip suckers are herbivorous (TL-2), but young bridgelip suckers are piscivorous (TL-3; Dauble, 1980). Notably, concentrations of iAs in large bridgelip suckers are substantially higher than measured for any other species of comparable size (Supporting Information, Table S1).

In addition to the relationship between weight and iAs concentration in tissue, several other lines of evidence support the hypothesis that concentrations of iAs in tissue decrease with increasing TL. The literature reports that arsenic bioaccumulates at lower TLs but that those concentrations are not transferred to upper-TL organisms (Chen & Folt, 2000; Chen et al., 2008; Cheng et al., 2013; Chetalat et al., 2019; Dovick et al., 2015; Lopez et al., 2016; Maeda et al., 1990; Revenga et al., 2012). Consistent with the literature, iAs tissue concentrations tended to increase with increasing surface water concentrations in TL-2 and TL-3 fish, though the increase was less pronounced in TL-3 and tended to decrease with increasing water concentration in TL-4 fish (Supporting Information, Figure S1).

Most of the arsenic in Idaho fish tissue was present as organic species (i.e., the iAs to tAs ratio is small), consistent with the literature that indicates that fish biotransform iAs to the nontoxic organic species of arsenic (Ciardullo et al., 2008, 2010; Cui et al., 2021; Pei et al., 2019). The iAs to tAs ratio in fish tissue is higher in lower-TL species, like the bridgelip sucker that feed primarily on aquatic algae, than in piscivorous upper-TL species like the trout and bass species (Figure 4), again consistent with patterns found in the literature (Ciardullo et al., 2008, 2010; Juncos et al., 2019). In addition, the iAs BAF declines with increasing iAs in surface water (Supporting Information, Figure S4), which also suggests that fish can regulate iAs in tissue and maintain a generally constant concentration across a wide range of water concentrations. Weight also appears to affect the iAs to tAs ratio in fish tissue, likely because of a link between size and TL for most species. As fish species such as trout and bass grow and their diets transition to primarily piscivorous, representative of higher TLs, the iAs to tAs ratio transitions from relatively higher in small and young fish to relatively lower in larger, older fish.

Combined, these lines of evidence point to regulation of iAs tissue concentrations by the biota in the aquatic food web, with both the concentration of iAs and the iAs to tAs ratio in tissue declining from lower to higher TLs in tissue of most fish species. This is consistent with biodimution or biodilution of tAs concentrations in aquatic food webs reported by other studies (Ng, 2005). The critical influence of the food web on iAs concentrations in aquatic tissues also means that BAFs (and BCFs) derived in laboratory settings (with smaller fish) need to be

interpreted with care. Unless those settings included the food-web effects described above, BAFs (or BCFs) derived from such studies are unlikely to predict concentrations of iAs (or other species of arsenic) in tissues of fish in natural settings.

In summary, the 2019 data set collected by Idaho represents the most comprehensive data set available to date on the concentration of iAs in fish tissue and the water column. It indicates that a statistically significant and biologically meaningful Idaho-specific BAF cannot be derived for iAs based on the current data set and that concentrations of iAs in Idaho fish tissue cannot currently be predicted based on the water column concentration.

Fish tissue concentrations reflect an integration of exposure to water over time, not just the concentration as reflected by a single colocated surface water sample. In situations where the concentration of a compound in water varies substantially over time, a single water measurement may fail to capture such variation and contribute to the variability of field-derived BAFs. That is unlikely to be the case for iAs in Idaho fish reported in the present study. A separate monthly surface water monitoring program (IDEQ, 2020) conducted by Idaho at the same time (August–October 2019) as the paired water and tissue sampling program described in the present study found that, at most sampling locations, the iAs concentration in surface water varied by <20% from month to month. In addition, BAFs varied substantially among fish collected from the same sampling location. This indicates that variability of iAs concentration in surface water over time is unlikely to be a substantial contributing factor to the observed variation in Idaho BAFs or an important source of uncertainty surrounding a BAF.

These findings have a substantial effect on setting HHWQC using the USEPA's standard HHWQC derivation methodology. That methodology prefers a TL-weighted BAF represented as a single numerical value (USEPA, 2003b) and is the methodology Idaho has used to establish an iAs HHWQC approvable by the USEPA. The critical issue in deriving a water column-based HHWQC using a BAF is that it assumes a relationship between water and fish. However, the Idaho data clearly show that such a relationship does not exist, which means that such a water column-based HHWQC has the potential to either over- or underprotect human health.

In the short term, USEPA guidance should provide flexibility for states to use alternative approaches to calculating BAFs, such as regression-based BAFs, that provide the best prediction of observed fish tissue concentrations and minimize the potential for over- or underprotection of human health. In the long term, the USEPA should examine alternative approaches to derive HHWQC for pollutants like iAs that do not fit the standard BAF paradigm. An alternate approach was used by the USEPA to develop an aquatic life water quality criterion for selenium. The USEPA concluded that the best science indicated that selenium toxicity in fish occurs primarily through transfer of selenium to eggs and subsequent reproductive effects. Thus, the USEPA developed a chronic criterion with four elements, reflecting the reproductive effects of selenium concentrations on fish species. The elements included a fish egg ovary element, a fish whole-body element, and a water column

element. The USEPA also noted that because the factors that determine selenium bioaccumulation vary among aquatic systems, site-specific water column criterion elements may be necessary (USEPA, 2016b).

Similar to the alternative approach taken to setting aquatic life water quality standards for selenium, an iAs fish tissue criterion may be the most appropriate water quality criterion for the protection of human health in instances where a relationship between iAs in tissue and water is absent. At a broader level, these findings present the USEPA and other regulatory agencies with an opportunity to refine the standard HHWQC methodology to account for the unique characteristics of iAs, and possibly other metalloids, and to assure that human health is protected. Such assurance will likely need to rely on something other than a water column concentration given that iAs water column and fish tissue concentrations are unrelated. A fish tissue-based criterion, as developed by the IDEQ, represents the most direct measure of the iAs concentration in fish. Monitoring of iAs concentrations in fish tissue can then be used to determine if the consumption of fish poses a risk to human health.

Supporting Information—The Supporting Information is available on the Wiley Online Library at <https://doi.org/10.1002/etc.5636>.

Acknowledgments—I. Wigger developed the field monitoring plan with the help of N. Paden and the negotiated rulemaking committee; I. Wigger and H. Stone traveled to rivers and streams throughout Idaho to collect the field samples. Field study design and data collection for the present study were funded by the Idaho Department of Environmental Quality. Funding for data analysis and manuscript development was provided by the Idaho Department of Environmental Quality, the J.R. Simplot Company, and Arcadis US.

Author Contributions Statement—**Emily B. Morrison:** Conceptualization; Data curation; Formal analysis; Methodology; Validation; Visualization; Writing—original draft; Writing—review & editing. **Jason Pappani:** Conceptualization; Data curation; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing—original draft; Writing—review & editing. **Alan Prouty:** Conceptualization; Funding acquisition; Writing—original draft; Writing—review & editing. **Holly M. McChesney:** Data curation; Formal analysis; Methodology; Writing—original draft; Writing—review & editing. **Paul D. Anderson:** Conceptualization; Formal analysis; Methodology; Validation; Writing—original draft; Writing—review & editing.

Data Availability Statement—All raw data used in this publication are presented in the Supporting Information.

REFERENCES

Agency for Toxic Substances and Disease Registry. (2007). *Toxicological profile for arsenic*. <https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf>

- Becker, G. (1983). *Fishes of Wisconsin*. University of Wisconsin Press.
- Behnke, R. (1992). *Native trout of western North America*. American Fisheries Society.
- Brooks Applied Labs. (2018). *Comprehensive quality assurance plan*. <https://brooksapplied.com/wp-content/uploads/download/CQAP.pdf>
- Burnham, K. P., Anderson, D. R., & Huyvaert, K. P. (2011). AIC model selection and multimodel inference in behavioral ecology: Some background, observations, and comparisons. *Behavioral Ecology and Sociobiology*, 65(1), 23–35.
- Chen, C. Y., & Folt, C. L. (2000). Bioaccumulation and diminution of arsenic and lead in a freshwater food web. *Environmental Science & Technology*, 34, 3878–3884.
- Chen, C. Y., Pickhardt, P. C., Xu, M. Q., & Folt, C. L. (2008). Mercury and arsenic bioaccumulation and eutrophication in Baiyangdian Lake, China. *Water, Air, and Soil Pollution*, 190, 115–127.
- Cheng, Z., Chen, K., Li, K.-B., Nie, X., Wu, S. C., Wong, C. K., & Wong, M. (2013). Arsenic contamination in the freshwater fish ponds of Pearl River delta: Bioaccumulation and health risk assessment. *Environmental Science and Pollution Research*, 20, 4484–4495.
- Chetlat, J., Cott, P. A., Rosabal, M., Houben, A., McClelland, C., Rose, E. B., & Amyot, M. (2019). Arsenic bioaccumulation in subarctic fishes of a mineimpacted bay on Great Slave Lake, Northwest Territories, Canada. *PLOS ONE*, 14(8), Article e0221361.
- Ciardullo, S., Aureli, F., Coni, E., Guandalini, E., Iosi, F., Raggi, A., Rufo, G., & Cubadda, F. (2008). Bioaccumulation potential of dietary arsenic, cadmium, lead, mercury, and selenium in organs and tissues of rainbow trout (*Oncorhynchus mykiss*) as a function of fish growth. *Journal of Agriculture and Food Chemistry*, 56, 2442–2451.
- Ciardullo, S., Aureli, F., Raggi, A., & Cubadda, F. (2010). Arsenic speciation in freshwater fish: Focus on extraction and mass balance. *Talanta*, 81, 213–221.
- Cubadda, F., Jackson, B. P., Cottingham, K. L., Van Horne, Y. O., & Kurzius-Spencer, M. (2017). Human exposure to dietary inorganic arsenic and other arsenic species: State of knowledge, gaps and uncertainties. *Science of the Total Environment*, 579, 1228–1239.
- Cui, D., Zhang, P., Liu, H., Zhang, Z., Song, Y., & Yang, Z. (2021). The dynamic changes of arsenic biotransformation and bioaccumulation in muscle of freshwater food fish crucian carp during chronic diet-borne exposure. *Journal of Environmental Sciences*, 100, 74–81.
- Dauble, D. (1980). Life history of the bridgelip sucker in the central Columbia River. *Transactions of the American Fisheries Society*, 109, 92–98.
- Dovick, M. A., Kulp, T. T., Arkle, R. S., & Pilliod, D. S. (2015). Bioaccumulation trends of arsenic and antimony in a freshwater ecosystem affected by mine drainage. *Environmental Chemistry*, 13, 149–159.
- Gray, R. H., & Dauble, D. D. (2001). Some life history characteristics of cyprinids in the Hanford Reach, mid-Columbia River. *Northwest Science*, 75, 122–136.
- Idaho Administrative Procedures Act. (2020). Water quality standards. Idaho Administrative Code. IDAPA 58.01.02.
- Idaho Department of Environmental Quality. (2015). *Idaho human health criteria technical support document*.
- Idaho Department of Environmental Quality. (2019). *Arsenic monitoring to support human health criteria adoption quality assurance project plan*. <https://www2.deq.idaho.gov/admin/LEI/api/document/download/15531>
- Idaho Department of Environmental Quality. (2020). *2019 Arsenic accumulation in fish tissue. Preliminary monitoring results*.
- Juncos, R., Arcagni, M., Squadrone, S., Rizzo, A., Arribere, M., Barriga, J. P., Battini, M. A., Campbell, L. M., Brizio, P., Abete, M. C., & Guevera, S. R. (2019). Interspecific differences in the bioaccumulation of arsenic of three Patagonian top predator fish: Organ distribution and arsenic speciation. *Ecotoxicology and Environmental Safety*, 168, 431–442.
- Liao, C.-M., Chen, B.-C., Singh, S., Lin, M.-C., Liu, C.-W., & Han, C.-C. (2003). Acute toxicity and bioaccumulation of arsenic in tilapia (*Oreochromis mossambicus*) from a blackfoot disease area in Taiwan. *Environmental Toxicity*, 18, 252–259.
- Liknes, G. A., & Graham, D. D. (1988). Westslope cutthroat trout in Montana: Life history, status, and management. In R. E. Gresswell (Ed.), *Status and management of interior stocks of cutthroat trout* (pp. 53–60). American Fisheries Society.
- Lopez, A. R., Hesterberg, D. R., Funk, D. H., & Buchwalter, D. B. (2016). Bioaccumulation dynamics of arsenate at the base of aquatic food webs. *Environmental Science & Technology*, 50, 6556–6564.

- Maeda, S., Ohki, A., Tokuda, T., & Ohmine, M. (1990). Transformation of arsenic compounds in a freshwater food chain. *Applied Organometallic Chemistry*, 4, 251–254.
- Maher, W. A., Foster, S. D., Taylor, A. M., Krikowa, F., Duncan, E. G., & Chariton, A. A. (2011). Arsenic distribution and species in two *Zostera capricorni* seagrass ecosystems, New South Wales, Australia. *Environmental Chemistry*, 8, 9–18.
- Mandal, B., & Suzuki, K. T. (2002). Arsenic round the world: A review. *Talanta*, 58, 201–235.
- Morrow, J. (1980). *The freshwater fishes of Alaska*. Animal Resources Ecology Library, University of British Columbia.
- Ng, J. C. (2005). Environmental contamination of arsenic and its toxicological impact on humans. *Environmental Chemistry*, 2, 146–160.
- Northwest Research Group. (2015). *Idaho fish consumption survey*. Idaho Department of Environmental Quality.
- Opalski, D. (2016, September 15). *EPA disapproval of Idaho's arsenic human health water quality criteria* [letter to B. Burnell, Idaho Department of Environmental Quality]. US Environmental Protection Agency.
- Otter, R. R., Bailey, F. C., Fortner, A. M., & Adams, S. M. (2012). Trophic status and metal bioaccumulation differences in multiple fish species exposed to coal ash-associated metals. *Ecotoxicology and Environmental Safety*, 85, 30–36.
- Pei, J., Zuo, J., Wang, X., Yu, J., Liu, L., & Fan, W. (2019). The bioaccumulation and tissue distribution of arsenic species in tilapia. *International Journal of Environmental Research and Public Health*, 16, 757–768.
- R: A language and environment for statistical computing. (2021). R Foundation for Statistical Computing. <https://www.R-project.org/>
- Rahman, M. A., Hasegawa, H., & Peter Lim, R. (2012). Bioaccumulation, biotransformation and trophic transfer of arsenic in the aquatic food chain. *Environmental Research*, 116, 118–135.
- Revenga, J. E., Campbell, L. M., Arribere, M. A., & Guevara, S. R. (2012). Arsenic, cobalt and chromium food web biodilution in a Patagonia mountain lake. *Ecotoxicology and Environmental Safety*, 81, 1–10.
- Scott, W., & Crossman, E. (1973). *Freshwater fishes of Canada* (Bulletin 184). Fisheries Research Board of Canada.
- 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., & Kinniburgh, D. G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry*, 17, 517–568.
- Sundbom, M., Meili, M., Andersson, E., Östlund, M., & Broberg, A. (2003). Long-term dynamics of Chernobyl ¹³⁷Cs in freshwater fish: Quantifying the effect of body size and trophic level. *Journal of Applied Ecology*, 40, 228–240.
- Systat. (2017). (Version 13.2.01) [Computer software]. Systat Software.
- Tanner, P. A., Leong, L. S., & Pan, S. M. (2000). Contamination of heavy metals in marine sediment cores from Victoria Harbour, Hong Kong. *Marine Pollution Bulletin*, 40, 769–779.
- US Environmental Protection Agency. (1980). *Ambient water quality criteria for arsenic* (EPA 440/5-80-021).
- US Environmental Protection Agency. (1996a). *Method 1638: Determination of trace elements in ambient waters by inductively coupled plasma-mass spectrometry*.
- US Environmental Protection Agency. (1996b). *Method 3050B: Acid digestion of sediments, sludges, and soils*.
- US Environmental Protection Agency. (1999). *Rapid bioassessment protocols for use in Wadeable streams and rivers* (EPA 841-B-99-002).
- US Environmental Protection Agency. (2000a). *Methodology for deriving ambient water quality criteria for the protection of human health* (EPA-822-00-004).
- US Environmental Protection Agency. (2000b). *Guidance for assessing chemical contaminant data for use in fish advisories: Vol. 1. Fish sampling and analysis* (EPA 823-B-00-007).
- US Environmental Protection Agency. (2002). *National recommended water quality criteria: 2002 human health criteria calculation matrix* (EPA-822-R-02-012).
- US Environmental Protection Agency. (2003a). *Technical summary of information available on the bioaccumulation of arsenic in aquatic organisms* (EPA-822-R-03-032).
- US Environmental Protection Agency. (2003b). *Methodology for deriving ambient water quality criteria for the protection of human health (2000) technical support document: Vol. 2. Development of national bioaccumulation factors* (EPA-822-R-03-03).
- US Environmental Protection Agency. (2014). *Estimated fish consumption rates for the US population and selected subpopulation (NHANES 2003–2010)* (EPA-820-R-14-002).
- US Environmental Protection Agency. (2016a). *Development of national bioaccumulation factors: Supplemental information for EPA's 2015 human health criteria update* (EPA-822-R-16-001).
- US Environmental Protection Agency. (2016b). *Aquatic life ambient water quality criterion for selenium—Freshwater* (EPA 822-R-16-006).
- Warton, D. I., & Hui, F. K. (2011). The arcsine is asinine: The analysis of proportions in ecology. *Ecology*, 92, 3–10.
- Williams, L., Schoof, R. A., Yager, J. W., & Goodrich-Mahoney, J. W. (2006). Arsenic bioaccumulation in freshwater fishes. *Human and Ecological Risk Assessment*, 12, 904–923.
- World Health Organization. (2017). *Guidelines for drinking water quality* (4th ed.).