global environmental solutions

Bioaccumulation Research Project

CSAP Society

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BIOACCUMULATION RESEARCH PROJECT

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ACRONYMS

BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BC CSR	British Columbia Contaminated Sites Regulation
BCoC	Bioaccumulative Contaminants of Concern
BHC	Hexachlorocyclohexane
BC MOE	British Columbia Ministry of Environment
BSAF	Sediment-Biota Bioaccumulation Factors
CEPA	Canadian Environmental Protection Act
COC	Contaminants of Concern
COPCs	Contaminants of Potential Concern
CSAP	Contaminated Site Approved Professional
CSM	Conceptual Site Model
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DERA	Detailed Ecological Risk Assessment
EcoRA	Ecological Risk Assessment
LOED	Lowest Observable Effects Dose
Kow	Octanol-Water Partitioning Coefficient
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PCDD/PCDF	Polychlorinated Dibenzodioxins/Polychlorinated Dibenzofurans
QSAR	Quantitative Structure Activity Relationship
SAB	Science Advisory Board
SedQC	Sediment Quality Criteria
TCDD	Tetrachlorodibenzodioxin
TCEQ	Texas Commission on Environmental Quality
TRG	Tissue Residue Guidelines
US EPA	United States Environmental Protection Agency
USGS	United States Geological Service

1.0 INTRODUCTION

Environmental contaminants can accumulate in human and ecological receptors through non-dietary uptake of site media as well as by ingestion of food items in which the contaminants have bioconcentrated. Some contaminants also biomagnify (i.e. tissue concentrations increase at higher trophic levels) as the contaminants are passed through the food chain. The degree of bioaccumulation and biomagnification for a given chemical is determined by the characteristics of each food web as well as by the characteristics of the chemical (TCEQ, 2014).

Ecological benchmarks are most often protective of risks associated with direct exposure and are not necessarily protective of bioaccumulation risks. Furthermore, identification of bioaccumulative substances is not consistently outlined in guidance documents. Therefore, a framework for evaluating bioaccumulation/biomagnification potential, specifically regarding the selection and assessment of bioaccumulative parameters, is needed to meet the expectations of the British Columbia Ministry of Environment (BC MOE) and to assist with Contaminated Sites Approved Professional (CSAP) submissions on low to moderate risk sites.

This research project was carried out through meetings with the BC MOE to frame working definitions of bioaccumulation processes and to develop an agreed upon approach for identifying bioaccumulation contaminants of concern. SLR also reviewed literature from provincial, federal and other jurisdictional sources for definitions and approaches to evaluate these substances. This report will provide the current working definitions to be used in CSAP risk assessment submissions, a summary of the literature review, and a proposed approach to identifying bioaccumulative substances.

1.1 Working Definitions

Recent discussions with the MOE have indicated that definitions and terminology provided in select Ministry procedures, guidance and protocol do not accurately represent the MOEs current views in the area of bioaccumulation/biomagnification. Based on these discussions, the following distinctions have been made for the purpose of this document:

- **Bioconcentration** - accumulation of contaminants in an organism from environmental media
- **Bioaccumulation** - accumulation of contaminants in an organism from all sources including food items
- **Biomagnification** - incremental increase in a contaminants concentration at subsequent levels within a food chain
- **Bioaccumulative** - includes both bioaccumulation and biomagnification processes **BUT** does not include bioconcentration processes

Figure 1 illustrates these concepts and should be used as a reference for discerning bioconcentrating versus bioaccumulative substances.

Risks associated with bioconcentration are evaluated during the assessment of direct contact doses from contaminated media. Therefore, bioconcentration is excluded from the bioaccumulative assessment process and food chain modelling is not required to evaluate associated risks.

The following framework is suggested as an approach for low to moderate risk sites which is both protective of potential bioaccumulative food chain effects and considers the framework and definitions of the British Columbia Contaminated Sites Regulation (BC CSR).

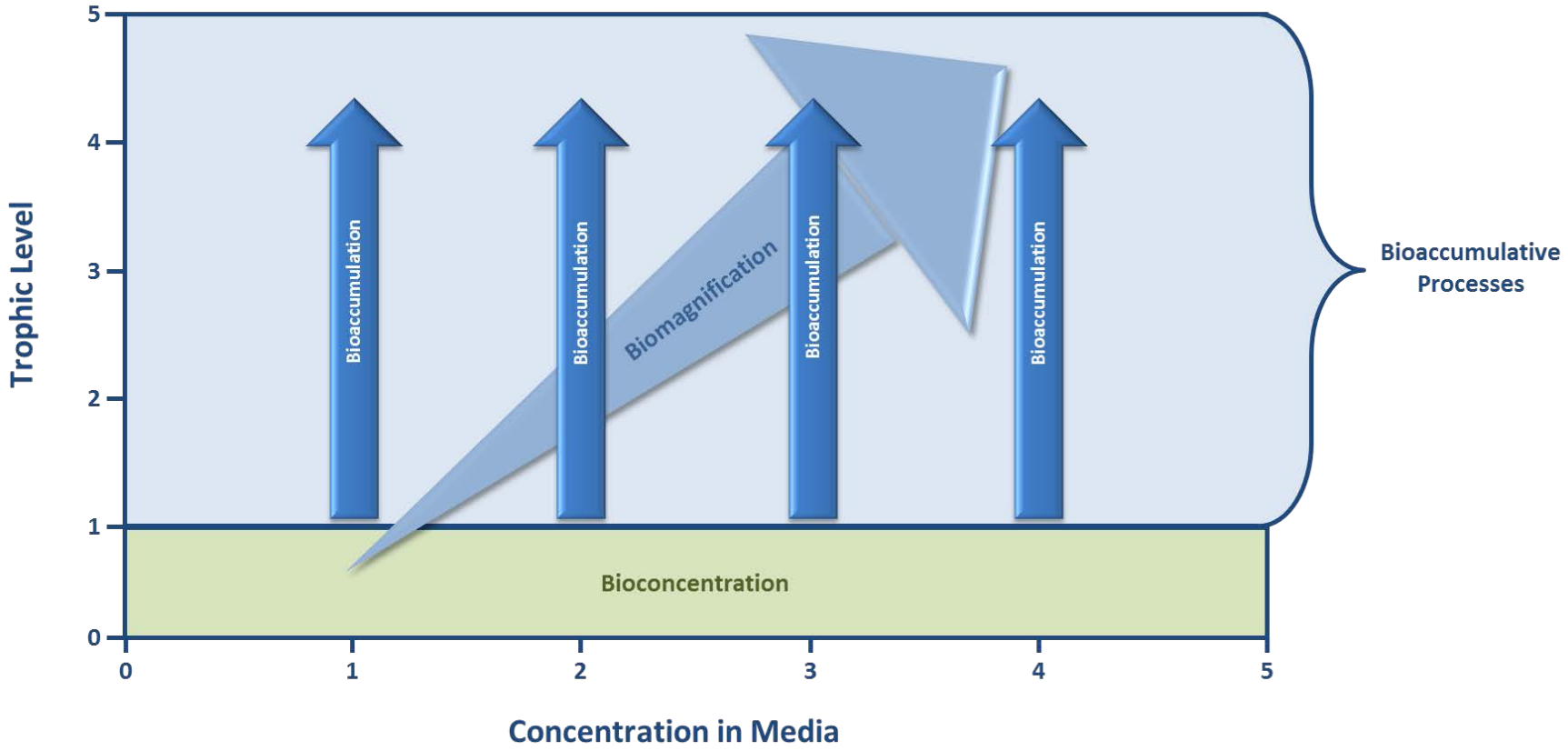


Figure 1: Schematic of Interrelationships Between Bioaccumulative, Bioaccumulation, Biomagnification and Bioconcentration

2.0 LITERATURE REVIEW

The literature review included compiling documents from provincial sources including the BC MOE and Science Advisory Board (SAB), as well as federal documents from Canadian and American sources.

2.1 BC MOE

The decisions made in the assessment and closure of contaminated sites in BC is guided by the definitions and guidance provided in the current BC CSR and associated procedure, protocol and guidance documents. The following details the definitions and guidance provided under the BC CSR in the assessment of bioaccumulative substances.

2.1.1 Current MOE Definitions

The definitions presented below provide the current basis for developing the procedure to identify and assess bioaccumulative substances for sites seeking MOE approval under the BC CSR.

BC CSR Procedure 8 – Definitions and Acronyms for Contaminated Sites

"Contamination" means the presence in soil, sediment, water or groundwater of

(a) a hazardous waste, or
(b) a substances prescribed for the purpose of paragraph (b) of the definition of "contaminated site"

in quantities or concentrations exceeding the criteria, standards or conditions prescribed for the purposes of the definition of "contaminated site".

"Contaminated Site" means an area of land in which the soil or any groundwater lying beneath it, or the water or the underlying sediment, contains

a) a hazardous waste, or
b) another prescribed substance

in quantities or concentrations exceeding prescribed risk based or numerical criteria or standards or conditions.

"**Bioaccumulative substances**[1]" means substances with any of the following characteristics: bioaccumulation factors [BAF] greater than 5,000; bioconcentration factor [BCF] greater than 5,000; or Log octanol-water partition coefficients [Log Kow] greater than 5.

[1] MOE is in the process of reviewing these definitions and updates are expected in future documents.

"**Food chain**" means a sequence of organisms in an ecological community in which each organism uses the next (usually lower) member of the sequence as a food source.

"**Food chain modelling**[1]" means the mathematical estimation for a substance of the extent of bioconcentration from environmental media and of the extent of bioaccumulation and biomagnification from food which occurs through a succession of organisms within a biological community or ecosystem.

2.1.2 Guidance

In addition to the definitions detailed above, additional guidance from the BC CSR regarding the assessment of bioaccumulative substances is provided below.

Protocol 1 – Recommended Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia

Section 8.1.1.1.2 Estimating Exposure with a Simple Food Chain Model

"For contaminants of concern that bioaccumulate, a food chain model is used to estimate the tissue concentration of the toxic material within the organism, if the concentration of a contaminant of concern was not measured in the food of an animal of interest. A step by step description of how to use a simple food-chain model follows……

"b) Determine the Kow for the organic contaminant(s) of concern using scientific literature or QSAR. If your organic contaminant of concern is not a methyl mercuric chloride compound and your Kow is less than 3.5, bioaccumulation is not a concern. Therefore it is not necessary to complete this worksheet. If the Kow of your contaminant is equal to or greater than 3.5, or if your contaminant is a mercuric chloride or other metal or metalloid compound, proceed to c)"

Step c) states: "Using your conceptual model, outline the potential exposure pathway from the contaminated media through the food chain to the endpoint receptor. Complete a separate pathway for each endpoint receptor and each contaminant of concern".

Following Step c), Protocol 1 provides guidance for estimating the concentration of a contaminant in food items using trophic level transfer calculations which require trophic level specific bioaccumulation factors (BAFs) and bioconcentration factors (BCFs). These terms are defined as follows in Protocol 1 (note: no mention of specific BAF or BCF values is made):

"Bioconcentration Factor (BCF) is the ratio of the amount of chemical in the tissue of an organism (plant or animal) to the amount in the water in which it is exposed. It assumes that the only exposure comes from the water. BCF = Tissue Concentration / Water Concentration"

"Bioaccumulation Factor (BAF) is the ratio of the amount of chemical in the tissues of an organism (plant or animal) to the amount in all exposure media (water, food, soil, etc.). BAF = Tissue Concentration / Food and Water Concentration"

Note: Although not explicitly stated in a definition, it may be presumed from the text that Protocol 1 considers organic compounds with a (log) Kow equal to or greater than 3.5 as well as metal or metalloid compounds to be bioaccumulative.

Section 8.4.2 Options for the Reduction of Uncertainty, Tier 2 EcoRA

Protocol 1 also offers the following guidance on conducting a more detailed ecological risk assessment. The following approaches aim to increase site-specific information thereby reducing uncertainty in the assessment.

1. "Use a specific conceptual model…….
2. "Conduct a detailed field study of the site. Field research can eliminate much of the uncertainty by obtaining specific data as to chemical concentrations, types of organisms inhabiting the area, and toxicity can be measured in detail using a variety of methods. Field studies are critical in obtaining appropriate data that can later be fed into exposure and food web modeling.
3. "Use a detailed food web or other exposure model. The data obtained from the field study should allow a detailed reconstruction of food web. By examining numbers of organisms and the concentration of chemical in their tissue, the rate of transfer and bioaccumulation can be determined rather than estimated. More detailed knowledge of the interrelationships of the plants and animals at a site will significantly reduce the uncertainty associated with the risk assessment."

Report on: Detailed Ecological Risk Assessment (DERA) in British Columbia Technical Guidance. September 2008. Prepared by Golder Associates Ltd.

The DERA guidance developed for the BC MOE provides a very brief mention on identifying bioaccumulative substances of concern. Although the information focuses on reviewing chemical properties to assess bioaccumulative potential, no guidance is given with respect to providing defining values.

Section 3.4. Step PF-3: Identify Contaminants of Potential Concern (COPCs)

"Some COPCs can be eliminated from consideration for certain pathways based on environment fate properties. For example, volatile organic compounds may be screened out of a foodweb bioaccumulation pathway, because these chemicals rarely accumulate in organism tissues at levels of environmental concern. Organic compounds with high Henry's Law Constant values (H) means they readily partition to air, while compounds with low Kow values means they tend "to be highly water soluble (and therefore readily excreted)."

"Defining Bioaccumulative Substances – MOE is developing policy on the identification of contaminants that should be considered strongly bioaccumulative and/or potential biomagnifiers. This will include consideration of Kow thresholds for organic substances. There are also various efforts to develop policy on defining bioaccumulation in other jurisdictions and which lines of evidence for risk evaluation are appropriate. The practitioner should consult MOE policy for updates to this issue"

Criteria for Managing Contaminated Sediment in British Columbia – Technical Guidance

As discussed in the *Criteria for Contaminated Sites – Criteria for Managing Contaminated Sediment in British Columbia, Technical Appendix,* the BC CSR Schedule 9 sediment criteria (SedQC) are direct effects-based and are not protective of bioaccumulation effects. The document states the need for bioaccumulation-based SedQC for several classes of bioaccumulative substances (including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCBs), polychlorinated dibenzodioxins and polychlorinated

dibenzofurans (PCDD/PCDFs) and organochlorinated pesticides) but recognizes that development of these criteria would require a variety of assumptions related to the food web and physical environment setting. Therefore, the document recommends that empirical contaminant measurements in benthos and prey items are used to identify potential regulatory concerns and that bioaccumulation effects are best assessed through the application of tissue residue guidelines (TRGs) and related approaches.

The guidance also discusses the use of TRGs to establish whole sediments remediation targets, protective of bioaccumulative effects, when used in conjunction with Ministry-approved sediment-biota bioaccumulation factors (BSAFs; where the remediation target = TRG ÷ BSAF). However, the criterion for the most sensitive designated use of the aquatic ecosystem must be selected as the remediation target for each COPC.

2.2 Science Advisory Board

In 2009, members of the BC Science Advisory Board (SAB) prepared a white paper to answer the question "When and what chemicals should be screened to include for evaluation of food chain uptake pathways?"

The paper indicated that, at the time, the BC MOE found food chain exposure pathways were being addressed in the risk assessment reports where appropriate. The paper recommended, for ecological receptors, all substances exceeding the generic or matrix standards protective of ecological receptors should be considered for potential food chain uptake. For human receptors at sites where ingestion of food may occur, all substances that have the potential to bioaccumulate in food items and that exceed a generic or matrix standard for the protection of intake of contaminated soil should be considered for food chain uptake.

2.3 Canadian Environmental Protection Act

Persistence and Bioaccumulation Regulations

"**A substance is bioaccumulative**

(*a*) when its **bioaccumulation factor** is equal to or greater than **5,000**;

(*b*) if its bioaccumulation factor cannot be determined in accordance with a method referred to in Section 5, when its **bioconcentration factor** is equal to or greater than **5,000**; and

(*c*) if neither its bioaccumulation factor nor its bioconcentration factor can be determined in accordance with a method referred to in Section 5, when the **logarithm of its octanol-water partition coefficient is equal to or greater than 5**."

2.4 United States Geological Service

Environmental Health – Toxic Substances Definition Page

"Bioconcentration is defined as the process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination.

"Bioaccumulation is defined as the accumulation of chemicals in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, and pore water in the sediment.

"Biomagnification is the result of the process of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of chemical from food to consumer, so that residue concentrations increase systematically from one trophic level to the next."

2.5 Texas Commission on Environmental Quality

Conducting Ecological Risk Assessments in Remediation Sites in Texas – Identification and Evaluation of Bioaccumulative COCs

In 2014, the TCEQ released a Draft version of a guidance document entitled Conducting Ecological Risk Assessments in Remediation Sites in Texas (TCEQ, 2014). This document provided direction on the entire ecological risk assessment process and included specific guidance for identifying and evaluating bioaccumulative contaminants of concern (COC). A number of definitions related to bioaccumulation were provided:

"Bioaccumulation - General term describing a process by which chemicals are taken up by an organism from both water and food containing the chemicals.

"Bioaccumulation factor - The ratio of the concentration of a chemical of concern in an organism to the concentration in the ambient environment at steady state.

"Bioaccumulative chemical of concern - A chemical of concern which has the tendency to accumulate in the tissues of an organism as a result of food consumption or dietary exposure and/or direct exposure (e.g., gills and epithelial tissue) to an environmental medium.

"Bioconcentration - Net accumulation of a chemical directly from an exposure medium into an organism.

"Biomagnification - An increase in tissue concentrations of chemicals in organisms as those materials pass up the food chain."

The TCEQ indicated bioaccumulative COCs can be present at concentrations below the applicable criteria protective of direct exposure within a given media but may still present risk to higher trophic levels. The document also makes a point of stating that the presence of bioaccumulative COCs in the environment does not indicate risks will occur but that evaluation of risk is warranted.

To begin the process of identifying organic bioaccumulative substances, the TCEQ reviewed lists detailing "variants" of bioaccumulative COCs as previously compiled by a variety of authorities including the United States Environmental Protection Agency, Environment Canada, United Nations Economic Commission for Europe and the North American Commission for Environmental Cooperation. The TECQ used the presence of organic parameters on multiple lists to identify predominant bioaccumulative substances. The presence of metals on TCEQ's bioaccumulative COC list was based on media-specific (soil, sediment and water) uptake factors (obtained from various sources). Metals were retained on the list for soil and sediment if the 90th percentile uptake factor was greater than 1 for soil plants and soil invertebrates, and benthic invertebrates, respectively. For surface water, metals were retained if the bioconcentration factor for aquatic invertebrates or fish was greater than 1000. The parameters retained the TCEQs final list are presented in Table 1 of this document.

In addition to the list, the TCEQ also provided the following guidance with respect to evaluating bioaccumulative COCs:

- In the event that the concentration of a bioaccumulative COC falls below an ecological screening benchmark but the COC has been recognized as a bioaccumulative COC in that medium, further evaluation of risk may be required and should take site-specific considerations into account.
- Exposure to most COCs in surface water at concentrations at or below their surface water criteria would (as indicated through calculations performed by the TCEQ's work group) be protective of wildlife with the exception of mercury, selenium, DDT and PCBs.
- Unless sufficient data are collected to identify the predominant metal species in the environment at the site, all metals should be assumed to be present in their most bioaccumulative form.

Finally, the TCEQ's multi-stakeholder group determined that COCs in sediment and surface water with log Kows between 3.8 and 8.0 may warrant bioaccumulation evaluation but those with a molecular weight of more than 700 would not, regardless of Kow.

3.0 PROPOSED APPROACH FOR BIOACCUMULATIVE CHEMICAL EVALUATION

The following sections describe the proposed approach for assessing bioaccumulative substances at low to moderate risk sites within the BC CSR framework.

3.1 Overview

A bioaccumulative chemical evaluation should be conducted when there is reason to believe that a given substance is bioaccumulative and may potentially pose unacceptable risk to human or ecological health in the environment.

The determination that bioaccumulative contaminants of concern (BCoCs) are present at a site and require assessment through quantification includes four main steps:

- Identification of contaminated media
- Identification of BCoCs (which may be conducted by either of the following options):

  - Comparison of chemistry data to pre-established BCoC lists
  - Comparison of chemical characteristics to bioaccumulative definition(s)

- Identification of receptors of concern at the site
- Completion of a conceptual site model (CSM) to identify if pathways between BCoCs and receptors are complete (justifications for incomplete or insignificant pathways should be described in the CSM)

Following the determination that BCoCs are present on the site and for which complete and significant pathways exist for one or more of the identified receptors, a bioaccumulative chemical assessment should be conducted.

3.2 Guiding Principles

In developing a consistent approach for identifying BCoCs, the definitions and guidance provided by the BC CSR with regard to characterizing contaminated sites, identifying bioaccumulative substances and recognizing the need for food chain assessments were reviewed in addition to discussing the various aspects of the approach with BC MOE. Based on this information, the following guiding principles were developed for low to moderate risk sites.

- Regardless of bioaccumulative characteristics, substances with concentrations below the applicable numerical standards/criteria or background concentrations in all media at a site are not included further in the bioaccumulative assessment process as the site is not considered to be contaminated with the given parameter.
- Considering the majority of bioaccumulation studies are related to sediment, parameters identified as being bioaccumulative in sediments should be considered for all other media unless the investigator/author can find supporting evidence to the contrary.
- Maximum measured concentrations (not statistical values) should be used to identify BCoCs. Statistics and spatial extent should only be considered in the development of the CSM and/or when quantifying risks associated with BCoC exposure.

3.3 Proposed Approach

The site investigation stage determines which substances on a site are present at concentrations exceeding any of the applicable (human health or ecological) standards/criteria and/or background concentrations. The remediation stage may include the decision to move forward with risk assessment. Practitioners will then conduct a Contaminant of Potential Concern screening to identify which substances are to be carried forward in the risk assessment. As illustrated in Figure 2, this screening should be two-fold: 1/ to identify parameter to be carried forward for the direct contact assessment and 2/ to identify parameters to be carried forward for the bioaccumulation assessment.

If detectable concentrations in media do not exceed CSR standards or if a substance is not listed in Table 1, the practitioner always has the option to complete a bioaccumulation assessment. This decision would be based on site-specific conditions and best professional judgement.

The following sections detail the process by which bioaccumulative contaminants of concern should be identified and carried forward in the risk assessment. The proposed approach is illustrated in Figure 3.

Details on the methods for screening and carrying out the direct contact assessment are not provided within this document.

3.3.1 Step 1: Identify Contaminated Media

Compile media-specific lists of substances exceeding the applicable standards/criteria.

Consideration of which media the site contaminants are located within may play a role in determining how the BCoCs are identified (Figure 2). Some examples of this are: (1) some metals may have a greater tendency to bioaccumulate in aquatic vs terrestrial ecosystems and (2) depending on the chemical and media, available information indicates that bioaccumulation is not a major contributor to overall body burden of particular receptors (e.g. recent work conducted by Texas showed bioaccumulation by wildlife from water is of negligible concern for most substances at concentrations below their state water quality criteria; TCEQ, 2014).

Rationale should be provided if a chemical is excluded as a potential BCoC within a given media.

Continue on to Step 2.

3.3.2 Step 2: Identifying BCoCs

Based on the findings of the literature review presented in Section 2.0, media-specific screening values protective of bioaccumulative effects are not readily available. Therefore, the next step in the assessment is to determine if a substance exceeding a numerical standard/criterion or a background concentration is considered to be bioaccumulative. This may be conducted for each substance by using one, or both, of the two suggested options presented below, both of which are acceptable to BC MOE.

- Option 1 provides a screening table to quickly identify substances considered to be bioaccumulative.
- Option 2 allows for a more rigorous approach to identifying or dismissing potentially bioaccumulative substances through a review of available literature and chemical properties.

The risk assessment practitioner may decide to use only one *or a combination of* the two options within a given risk assessment. As well, Option 1 may each be used to identify BCoCs then Option 2 may further be used to refine the final BCoC list. Alternatively, a practitioner may opt to use Option 2 from the onset of the project.

It is of note that although proposed, bioaccumulative-based guidelines have not yet been developed for environmental media. Once developed, these guidelines should be reviewed to determine if they are suitable for use at the site of interest and, if so, may be used to identify BCoCs.

As discussed previously, it is assumed that the direct contact assessment includes bioconcentration and should always be conducted regardless of if the substance is identified as a BCoC (Figure 2).

3.3.2.1 *Option 1: Consult Pre-Established BCoC Lists*

A substantial amount of work has been conducted by multiple regulatory agencies and interest groups to compile information from literature studies, laboratory tests, etc. related to the identification of bioaccumulative compounds of concern. The work has often been summarized as lists identifying priority BCoCs. A description of the select BCoCs lists, their sources and compilation criteria is given in Table A. It is of note that although the criteria by which each of these lists has been produced has varied (e.g. target log Kow values between 3.5 and 5 have been used), several substances are consistently identified on all lists thereby providing a good indication that these substances are of significant bioaccumulation concern. Consequently, for the purpose of this document, substances included on each list are presented (Table 1 following the text) and may act as a starting point for identifying bioaccumulating and biomagnifying substances.

If a substance is indicated in Table 1, further bioaccumulative assessment is required regardless of medium (unless scientific rationale can be provided, see Option 2), proceed to Step 3.

Substances indicated in Table 1 can be eliminated from further consideration, on a case-by case basis, by providing appropriate scientific rationale. This would be appropriate when a substance within a given media at a site has been identified as a BCoC based on Table 1, but the basis upon which the Table 1 study criteria were developed do not align with the media of interest or food chain characteristics at the site. See Option 2 for additional details.

If the compound has not been identified as a BCoC in Table 1, no further action required for assessment of bioaccumulation/biomagnification.

However, a discussion of the potential for bioaccumulation and biomagnification may be discussed in the uncertainty section of the risk assessment.

Exception: For the purposes of Protocol 13, use Procedure 8 definition(s).

Table A: Sources and Criteria for Select Bioaccumulative Contaminants of Concern (BCoCs) Lists

Source	Criteria
BC MOE. *Criteria for Contaminated Sites – Criteria for Managing Sediments in British Columbia.*	Tissue Residue Guidelines for bioaccumulative substances adopted from the Canadian Council of Ministers of the Environment.
E. Hoffman for the Agencies of the Dredged Material Management Program. *The Technical Basis for Revisions to the Dredged Material Management Program's Bioaccumulative Contaminants of Concern List.* January, 2007[1]	Identified as Primary BCoCs if: - Log Kow >3.5 *and* tissue monitoring data exceeded Lowest Observable Effects Dose (LOED) or - Log Kow >3.5 *and* parameters was measured more than 10% of regional tissue monitoring data *and* toxicity information is available *and* parameter is known to be human or eco-toxic
Texas Commission on Environmental Quality. *Conducting Ecological Risk Assessments at Remediation Sites In Texas.* Draft January 2014.	Bioaccumulative parameters identified based on: - Uptake factors > 1 - BCF >1000 - Log Kow >3.8 and <8.0 - Molecular weights <700 - Professional judgement
Ed Corl. *Bioaccumulation in the Ecological Risk Assessment (ERA) Process.* August 2001.	Bioaccumulative parameters identified based on: - Half-life > 30 days - BCF > 1000 - Log Kow > 4.2

Notes:
[1]Hoffman, 2007 went further than simply establishing a list of known BCoCs, but placed substances on one of four lists depending on the amount of available information and a weight-of-evidence indicating their potential to bioaccumulate, prevalence in the region, and toxicity. Only the parameters listed on List 1 (Primary BCoCs) were included in this assessment.

3.3.2.2 *Option 2: Evaluate Chemical Properties*

Option 2 may be selected instead of Option 1 for identifying BCoCs. Option 2 may be used as rationale for dismissal of a substance that has been identified using Option 1 (listed in Table 1) by providing a review of the log Kow, BCF and/or BAF information. Option 2 can also be used by a risk practitioner to evaluate bioaccumulative potential of a substance not identified in Table 1 but the practitioner has determined the need for a risk assessment. Option 2 allows for further evaluation of chemical properties that may be desired by the investigator/author to evaluate a contaminants bioaccumulative potential within a given food chain. If so, the log Kow, BCF and BAF values should be used to identify bioaccumulative substances per the definitions provided by the TCEQ (2014). This reference selection is supported by BC MOE and is the most recent reference.

Log Kow values describe the hydrophobicity, and thereby the bioaccumulation potential, of organic compounds (US EPA, 2000). Due to measurement errors resulting from experimental methods or theoretical calculations used in the derivation, literature-reported log Kow values are often variable (Hoffman, 2007). However, log Kow values are often preferentially used in predicting bioaccumulative potential as compared to BAFs or BCFs since they are more readily available and are not specific to a given media, trophic level or species group.

Although BAFs and BCFs provide a better indication of a parameter's propensity to bioaccumulate, these values can also vary based on derivation methods (estimated or measured), model species and measurement method. Overall, BAFs are generally considered

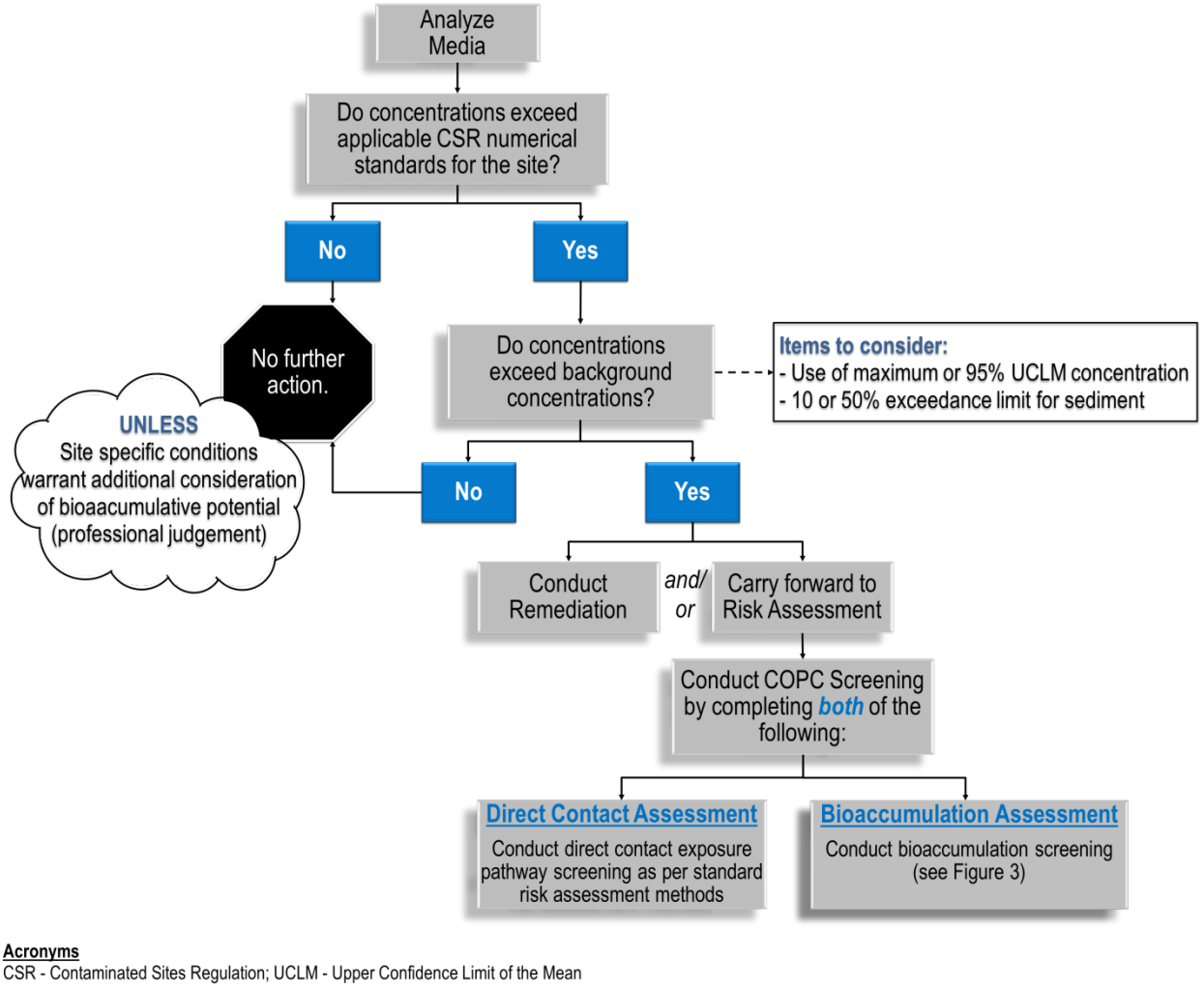
better indicators of bioaccumulative potential as these values consider intake associated with both environmental media exposure and food ingestion (Hoffman, 2007; USEPA, 2000).

Overall, it is important to carefully select and remain consistent with respect to which variable is used to determine bioaccumulative potential at a given site, in particular with respect to a given trophic level and for a given media. A table providing all values, resources and rationale for including a compound as a BCoC should be provided and adequately referenced in the risk assessment.

If log Kow, BAF and/or BCF information cannot be obtained, a discussion of the potential for bioaccumulation and biomagnification may be discussed in the uncertainty section of the risk assessment.

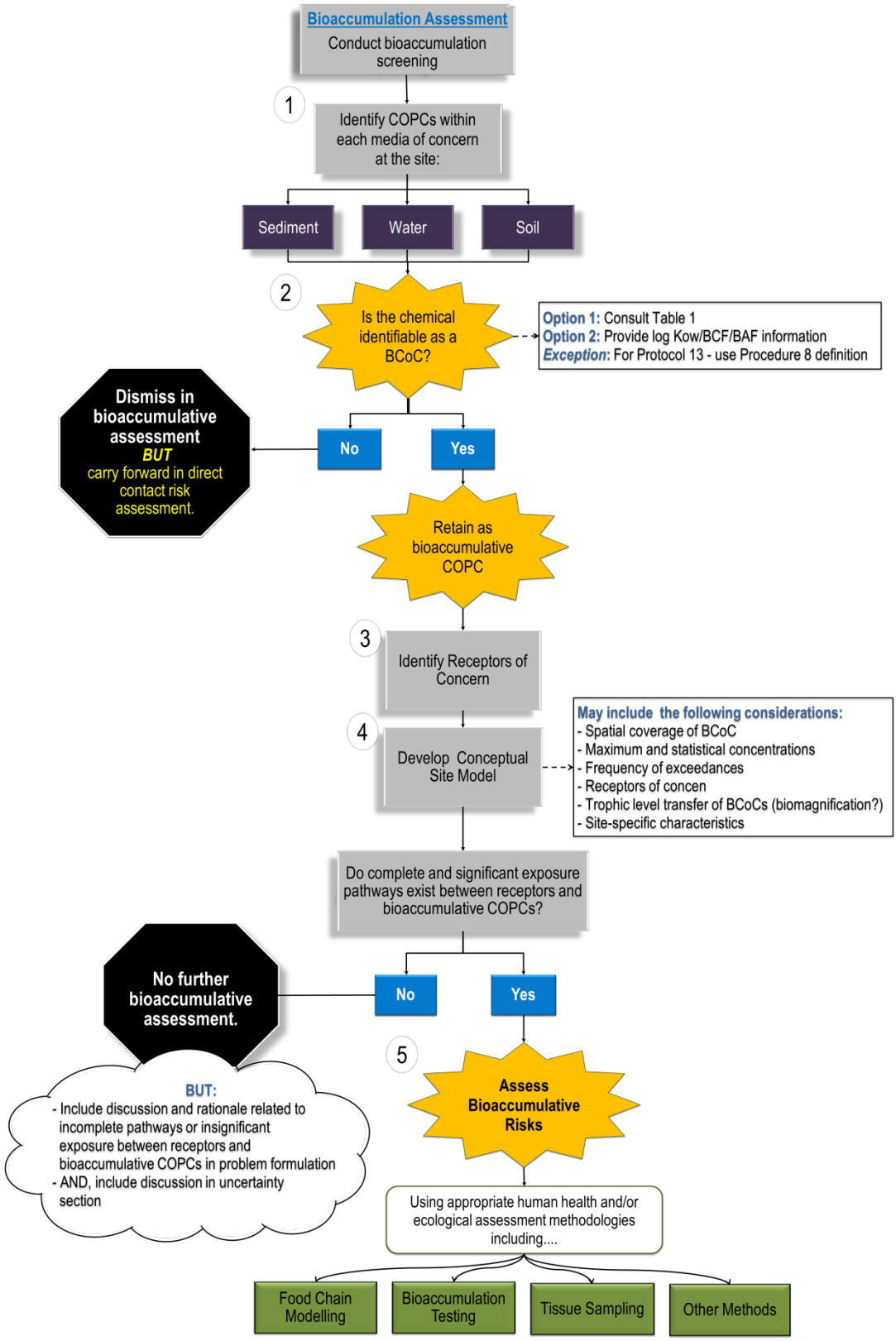
If the compound has been identified as a BCoC, proceed to Step 3.

If the compound has not been identified as a BCoC, no further action required for assessment of bioaccumulation/biomagnification.



Acronyms
CSR - Contaminated Sites Regulation; UCLM - Upper Confidence Limit of the Mean

Figure 2: Generic Site Investigation Process for Identifying the Need for Risk Assessment and a Bioaccumulation Assessment



Acronyms
BAF - Bioaccumulation Factor; BCF - Bioconcentration Factor; BCoC - Bioaccumulative Contaminant of Concern; BSAF - Sediment-Biota Bioaccumulation Factor; COPC - Contaminant of Potential Concern; Kow - Octanol-Water Partitioning Coefficient; TRV - Toxicity Reference Value

Figure 3: Decision Criteria to Identify and Address BCoCs within a Risk Assessment

3.3.3 Step 3: Identify Receptors of Concern

Considering that a large amount of guidance is available from multiple sources on the selection of receptors of concern, this step will not be discussed at length in this document.

However, an important factor to keep in mind is that the food web should be carefully evaluated so that all potential trophic levels are identified and representative receptors are optimally selected.

Proceed to Step 4.

3.3.4 Step 4: Develop Conceptual Site Model

The CSM plays a critical role in the decision making process to include or exclude bioaccumulative substances from quantification in the risk assessment. As with CSMs developed for the assessment of complete exposure pathways for direct effects, the spatial extent of the bioaccumulative parameter across the site, types of receptors, routes of exposure and chemical specific information among other factors, will lead to the determination of which BCoCs need to be considered for quantification. If BCoCs are present on a site but incomplete or insignificant pathways are identified for one or more of the receptors, adequate justification should be provided in the text.

On the basis that the bioaccumulation and biomagnification of a given substance may be influenced by the ecosystem (aquatic or terrestrial) or types of receptors in a food chain, some of the factors which may be considered in the development of the CSM include:

- Types of receptors within food chain (invertebrates, fish, mammals, etc.)
  e.g. Do the receptor groups metabolize a given BCoC differently?
- Trophic level of each receptor
  e.g. benthic vs pelagic feeders
- Trophic levels transfer of BCoCs
  e.g. Does the BCoC biomagnify?
- Physico-chemical site characteristics that could modify contaminant bioavailability
  e.g. sediment grain size, organic carbon content, AVS/SEM

Examples of how CSMs may be used to determine the need for quantification

- *Although PAHs may be identified as a bioaccumulative substance in sediments and water at a site, literature has shown that these substances are readily metabolized by fish, thus bioaccumulative assessment for PAHs may not be necessary for fish or receptors consuming fish.*
- *By evaluating the spatial sampling coverage across the site and the expected receptors of concern, the CSM may be used to determine if the area of contamination likely presents a significant and on-going source of BCoC uptake.*
- *By considering all the available data, the CSM may be used to determine if the maximum BCOC concentration is considered to be representative of site conditions or if another statistically derived concentration would better represent site conditions.*

If complete exposure pathways have been identified, proceed to Step 5.

If exposure pathways are incomplete or insignificant, no further action.

3.3.5 Step 5: Conduct Bioaccumulative Assessment

Once a chemical has been identified as a BCoC and complete exposure pathways exist for one or more of the identified receptors, a bioaccumulative assessment will need to be conducted. This assessment can be carried out using a variety of methods (alone or in combination), some which are listed below.

- Food Chain Modelling
- Tissue Sampling
- Metal Speciation Testing
- Bioaccumulation Testing
- Comparison of Measured or Modelled Tissue to TRGs

The most appropriate method(s) for the assessment of risks associated with bioaccumulative substances will vary based on site-specific conditions. Therefore, the assessment approach is left up to the individual practitioners to determine taking into consideration advice provided in Protocol 1 and DERA.

Finally, the bioaccumulative assessment should address cumulative exposure from all site media and food sources.

4.0 REFERENCES

Corl, E. 2001. Bioaccumulation in the Ecological Risk Assessment (ERA) Process. Issue Paper, Navy Guidance for Conducting Ecological Risk Assessments. Naval Facilities Engineering Command, Atlantic Division. August 2001.

British Columbia Ministry of the Environment (BC MOE). 1998. Protocol 1: Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia. January 1998. Available on-line at http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/protocols/protocol-1.pdf.

British Columbia Ministry of the Environment (BC MOE). 2014. Environmental Protection Division. Procedure 8 – Definitions and Acronyms for Contaminated Sites. January 14, 2014. Available on-line at http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/procedures/procedure-08-2014.pdf.

British Columbia Ministry of Water, Land and Air Protection. (undated). Criteria for Contaminated Sites. Criteria for Managing Contaminated Sediment in British Columbia. Technical Appendix. Available on-line at http://www.env.gov.bc.ca/epd/remediation/standards_criteria/.

Golder Associates Ltd. 2008. Detailed Ecological Risk Assessment (DERA) in British Columbia – Technical Guidance. Final – 2008 Revision. September 3, 2008. Available on-line at http://www.sabcs.chem.uvic.ca/DERA2008.pdf.

Hoffman, E. 2007. The Technical Basis for Revisions to the Dredged Material Management Program's Bioaccumulative Contaminants of Concern List. Prepared for the Agencies of the

Dredged Material Management Program. January 5, 2007. Available on-line at http://www.nws.usace.army.mil/Portals/27/docs/civilworks/dredging/Updates/2007-Final_BCOC_Technical_Appendix_010807.pdf.

Texas Commission on Environmental Quality (TCEQ). 2014. Conducting Ecological Risk Assessments at Remediation Sites In Texas. Draft January 2014. Available on-line at https://www.tceq.texas.gov/assets/public/remediation/trrp/rg263-draft.pdf.

United States Environmental Protection Agency (US EPA). 2000. Bioaccumulation Testing And Interpretation For The Purpose Of Sediment Quality Assessment. Status and Needs. February, 2000. Available on-line at http://water.epa.gov/polwaste/sediments/cs/biotesting_index.cfm.

5.0 STATEMENT OF LIMITATIONS

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Table 1: Listed Bioaccumulative Chemicals of Concern (BCoCs) from Select Sources

Substance	BC TRGs	Hoffman, 2007	TCEQ, 2014	Corl, 2001
Metals				
Arsenic		x		x
Cadmium		x	x	x
Chromium		x	x	x
Copper		x	x	x
Lead		x	x	x
Mercury	x	x	x	x
Nickel		x	x	x
Selenium		x	x	x
Silver		x		x
Thallium			x	
Tributyltin		x	x	x
Zinc		x	x	x
Pesticides and PCBs				
Aldrin			x	x
Chlordane		x	x	x
Chlorphyrifos				x
Dichlorodiphenyldichloroethane (DDD)	x		x	x
Dichlorodiphenyldichloroethylene (DDE)	x		x	x
Dichlorodiphenyltrichloroethane (DDT)	x		x	x
Diazinon				x
Dicofol				x
Dieldrin			x	x
Disulfoton				x
alpha-Endosulfan				x
beta-Endosulfan				x
Endrin			x	x
Ethion				x
Heptachlor			x	x
Heptachlor epoxide			x	x
alpha-Hexachlorocyclohexane (a-BHC)				x
beta-Hexachlorocyclohexane (b-BHC)				x
delta-Hexachlorocyclohexane (d-BHC)				x
gamma-Hexachlorocyclohexane (g-BHC, lindane)				x
Methoxychlor				x
Mirex			x	x
Oxyfluorfen				x

Table 1: Listed Bioaccumulative Chemicals of Concern (BCoCs) from Select Sources

Substance	BC TRGs	Hoffman, 2007	TCEQ, 2014	Corl, 2001
Pentachloronitrobenzene				x
Permethrin				x
S-fenvalerate				x
Terbufos				x
Toxaphene			x	x
Trifluralin				x
PCBs	x	x	x	x
Semi-Volatiles				
Dioxins		x	x	x
Furans		x	x	x
Hexachlorobenzene		x	x	x
Hexachlorocyclehexane			x	
Octachlorostyrene			x	
Pentachlorophenol		x	x	x
PAHs				
Acenaphthene				x
Acenaphtylene				x
Anthracene				x
Benzo(a)anthracene				x
Benzo(a)pyrene				x
Benzo(b)fluoranthene				x
Benzo(g,h,i)perylene				x
Benzo(k)fluoranthene				x
Chrysene				x
Dibenzo(a,h)anthracene				x
Fluoranthene				x
Fluorene				x
Indeno(1,2,3-c,d)pyrene				x
Phenanthrene				x
Pyrene		x		x
Dioxins				
2,3,7,8-TCDD	x			

Table 1: Listed Bioaccumulative Chemicals of Concern (BCoCs) from Select Sources

Substance	BC TRGs	Hoffman, 2007	TCEQ, 2014	Corl, 2001
Chlorinated Aromatic Hydrocarbons				
1,2-Dichlorobenzene				x
1,3-Dichlorobenzene				x
1,4-Dichlorobenzene				x
Hexachloroethane				x
Hexachlorobutadiene				x
Hexachlorocyclopentadiene				x
1,2,4,5-Tetrachlorobenzene				x
1,2,3,4-Tetrachlorobenzene				x
Tetrachloroethane				x
1,2,4-Trichlorobenzene				x

Notes:
BHC - Hexachlorocyclohexane
BC TRG – British Columbia Tissue Reference Guidelines
DDD - Dichlorodiphenyldichloroethane
DDE - Dichlorodiphenyldichloroethylene
DDT - Dichlorodiphenyltrichloroethane
PAH - Polycyclic Aromatic Hydrocarbons
PCBs - Polychlorinated Biphenyls
TCDD - Tetrachlorodibenzodioxin
TCEQ - Texas Commission on Environmental Quality

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