

Modernizing British Columbia's Sediment Standards

Objective Statement: To present a comprehensive scoping plan for developing a scientific framework for updating the Contaminated Sites Regulation (CSR) Schedule 3.4 generic numerical sediment standards for British Columbia (BC), integrating findings from preliminary scientific research, a jurisdictional scan of other government agencies, and insights from multifaceted community and stakeholder engagement activities.

I. Introduction

A. Background and Context:

Sediments are fundamental components of aquatic ecosystems in BC, providing critical habitat for benthic organisms, influencing nutrient cycling, and mediating the fate and transport of substances within water bodies (Apitz, 2012). This understanding is increasingly recognizing sediment not just as a sink for contaminants, but as a dynamic and integral component that sustains numerous ecosystem services, providing benefits to both the environment and human well-being (Apitz, 2012). However, due to their physical and chemical properties, sediments also act as significant sinks for a wide range of anthropogenic contaminants (Apitz, 2012). Over time, these accumulated contaminants can be released back into the water column or taken up by organisms, acting as a secondary source of pollution and posing long-term risks to ecological and human health (Apitz, 2012). The comprehensive framework proposed by the Sediment-Ecosystem Regional Assessment (SEcoRA) underscores that neglecting such risks can undermine the long-term viability of the ecosystem services provided by healthy sediments, thus necessitating a modernized approach to sediment quality management (Apitz, 2012). Effective environmental management therefore requires robust tools and guidelines to assess sediment quality and manage associated risks.

In BC, the *Environmental Management Act* (EMA; BC, 2025a), CSR (BC, 2003a), and Protocols determine the requirements for site remediation (BC, 2025b). Schedule 3.4 of the CSR provides generic numerical sediment standards, which are simply referred to as “sediment standards” however they are abbreviated as SedS in later sections of this report. These sediment standards were established to protect aquatic life and are applied across different aquatic settings – freshwater, marine, and estuarine – and differentiate between 'sensitive sediment use' and 'typical sediment use', reflecting differing protection goals.

The current sediment standards are largely based on approaches and data from the late 1990s and early 2000s, detailed in technical documents such as the Ministry of Water,

Lands and Parks (MWLAP, 2003) and MacDonald et al. (2003). Since their development, there have been substantial global advancements in understanding sediment toxicology including significant improvements regarding the availability of relevant data, the critical role of bioavailability, and the complex pathways of contaminant bioaccumulation and food web transfer.

This report outlines a comprehensive, science-based framework for updating BC's sediment standards to reflect the state of sediment science as of 2025, ensuring adequate protection for the province's diverse aquatic resources, including higher-trophic wildlife and human consumers of aquatic foods. The overarching purpose of this report is to propose a scientifically defensible and practical framework for reviewing and updating the sediment standards.

B. Problem Statement/Rationale for Review:

A review and modernization of BC's sediment standards are necessary due to several key limitations related to the derivation of the standards. These standards were derived using methodologies that primarily focus on direct toxic effects on a few select benthic invertebrates and do not adequately address indirect risks via food web transfer to wildlife and humans. MWLAP (2003) explicitly acknowledged that the effects-based Sediment Quality Criteria (SedQC) do not provide an adequate basis for assessing risks to piscivorous wildlife or human health associated with the food web transfer of persistent, bioaccumulative substances, recommending the separate application of tissue residue guidelines (TRGs) (MWLAP, 2003). In 2017, the CSR Omnibus Amendment renamed the SedQC to sediment standards, but the values remained unchanged (BC, 2017a).

Furthermore, the current standards do not incorporate substance bioavailability, which can lead to unnecessary conservatism in screening. Factors such as sediment organic carbon (OC) and Acid Volatile Sulfides (AVS), known to influence bioavailability (ITRC, 2011), are not routinely integrated into the application of sediment standards. The standards also lack coverage for many emerging contaminants of concern, such as Per- and Polyfluoroalkyl Substances (PFAS), pesticides, N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD), and microplastics, and have not been regularly updated to keep pace with scientific advancements in ecotoxicology and risk assessment. This review aims to address these gaps in the development of a robust, scientifically current, and holistically protective framework for review and updating of the sediment standards.

C. Report Objectives and Scope:

The specific objectives of this report and the initiative it describes are:

- To review the derivation and limitations of the current sediment standards.
- To identify and synthesize the best available scientific concepts, techniques, and approaches for developing modern sediment standards.
- To conduct a jurisdictional scan of sediment quality management frameworks in other relevant Canadian and international jurisdictions to identify best practices.
- To outline a plan for community and stakeholder engagement to gather diverse input.
- To propose a scientifically defensible, comprehensive, and practical framework for developing updated sediment standards for freshwater, marine, and estuarine environments in BC, explicitly incorporating protection for benthic ecosystems, as well as for wildlife and human consumers via food-chain transfer and bioaccumulation.

The scope of work encompasses preliminary scientific research, a review of international regulatory approaches, planned community engagement, and the initial development of a proposed framework for updating and modernizing the sediment standards.

D. Methodology Overview:

The approach taken to inform this report and the proposed framework is multi-faceted, involving:

- **Preliminary Scientific Research:** Analysis of the derivation and limitations of existing BC sediment standards, and a high-level review of current scientific literature on sediment toxicology, bioavailability, bioaccumulation, food web modeling, and risk assessment methodologies.
- **Jurisdictional Scan:** A comparative review of sediment standard frameworks and derivation methodologies from leading Canadian provinces, federal Canadian agencies, the federal and state-level agencies from the United States, the European Union, Australia/New Zealand, and select Asian countries.
- **Community and Stakeholder Engagement (Planned):** Future activities will include an online public survey and targeted workshops and presentations with scientific experts (e.g., at the Canadian Ecotoxicity Workshop) to gather input and feedback.
- **Framework Development:** Synthesis of the above information to develop an interim proposed framework for modernizing BC's sediment standards.

E. Report Structure:

This report is organized into seven main sections. Section I provides an introduction, rationale, objectives, and scope. Section II details the preliminary scientific research findings, including an analysis of existing BC sediment standards, identified issues, and

a review of best available science. Section III presents the jurisdictional scan of sediment quality management approaches. Section IV outlines the planned community and stakeholder engagement activities. Section V describes the interim proposed framework for modernized sediment standards. Section VI, Conclusions and Recommendations, will be developed upon completion of all research and engagement. Section VII lists the references, and Section VIII lists the appendices.

II. Preliminary Scientific Research Findings

A. BC CSR Schedule 3.4 Sediment Standards:

Derivation Approach:

The generic numerical sediment standards in BC's CSR Schedule 3.4 were formally established based on work conducted in the early 2000s. This work culminated in key documents such as the "*Criteria for Managing Contaminated Sediment in British Columbia: Technical Appendix*" (MWLAP, 2003) and "*Development and Applications of Sediment Quality Criteria for Managing Contaminated Sediment in British Columbia*" (MacDonald et al., 2003). The derivation approach involved several distinct steps (MWLAP, 2003; MacDonald et al., 2003):

1. **Establishment of Sediment Management Objectives (SMOs):** Two tiers of sites were defined to guide the protection levels:
 - "Sensitive Contaminated Sites" (SedQC_{SCS}): The SMO for these sites was to restore sediments to facilitate productive and diverse benthic macroinvertebrate communities in the near-term and to minimize risks to organisms at higher trophic levels in the food web. The aim was a low probability (approximately 20%) of observing significant adverse effects (e.g., EC₂₀) (MacDonald et al., 2003; MWLAP, 2003).
 - "Typical Contaminated Sites" (SedQC_{TCS}): The SMO for these sites was similar but focused on the longer-term, with a moderate probability (approximately 50%) of observing significant adverse effects (e.g., EC₅₀) (MacDonald et al., 2003; MWLAP, 2003).
2. **Identification of Preliminary Benchmarks:** The Canadian Council of Ministers of the Environment (CCME) Probable Effect Levels (PELs) from their 1999 guidelines (CCME, 1999) were adopted as preliminary benchmarks for the BC sediment standards. This decision was based on the general consistency of the PELs' narrative intent with the established SMOs (MacDonald et al., 2003; MWLAP, 2003; CCME, 1999).
3. **Development of Concentration-Response Relationships:** To refine these benchmarks, matching sediment chemistry and toxicity data were compiled, primarily from North American amphipod tests (e.g., *Hyalella azteca* for freshwater; *Ampelisca abdita* and *Rhepoxynius abronius* for marine environments). Mean

PEL-quotients (PEL-Qs) were calculated for contaminant mixtures, and logistic regression models were developed to relate these mean PEL-Qs to the observed incidence of toxicity (MacDonald et al., 2003; MWLAP, 2003).

4. Refinement of Preliminary Benchmarks (Derivation of Numerical SedQC):

- For SedQC_{SCS} (sensitive contaminated sites), the PELs for individual contaminants of potential concern (COPCs) were multiplied by the mean PEL-Q value that corresponded to a 20% probability of observing toxicity in freshwater amphipods (P_{20} freshwater = 0.62). This adjustment factor was applied to both freshwater and marine PELs because a P_{20} value for marine sediments could not be determined at the time (MacDonald et al., 2003; MWLAP, 2003).
- For SedQC_{TCS} (typical contaminated sites), the PELs for individual COPCs were multiplied by the average of the mean PEL-Q values corresponding to a 50% probability of observing toxicity in freshwater and marine amphipods (P_{50} average = 1.2) (MacDonald et al., 2003; MWLAP, 2003).

Therefore, the current sediment standards are fundamentally CCME PELs (CCME, 1999) adjusted by factors derived from specific amphipod toxicity datasets to align with pre-defined risk probabilities for benthic effects.

Intended Protection Level and Scope:

The primary intended protection level of the existing sediment standards is for benthic invertebrates (MacDonald et al., 2003; MWLAP, 2003). The derivation methodology is explicitly linked to the survival and growth responses of these sediment-dwelling organisms. While the SMOs included a general aim to minimize risks to organisms at higher trophic levels, the derivation process itself did not directly or systematically incorporate bioaccumulation pathways or specific protection goals for wildlife or human consumers of aquatic biota (MacDonald et al., 2003; MWLAP, 2003).

"Criteria for Managing Contaminated Sediment in British Columbia: Technical Appendix" explicitly states, "...these effects-based SedQC may not provide an adequate basis for assessing risks to piscivorous wildlife or human health that are associated with food web transfer of persistent, bioaccumulative substances... Currently, bioaccumulation risks are most effectively assessed through the application of TRGs and related approaches" (MWLAP, 2003).

Consequently, the scope of the sediment standards in Schedule 3.4 is predominantly limited to direct toxicity to sediment-dwelling organisms, with separate, non-integrated TRGs suggested for addressing bioaccumulation concerns (MWLAP, 2003).

B. Identified Issues and Deficiencies with Existing Sediment Standards:

A thorough review, incorporating insights from contemporary scientific literature and

regulatory advancements, reveals several issues and deficiencies with the existing sediment standards:

- **Lack of Protection for Non-Benthic Receptors (Direct Exposure):** While designed to protect benthic invertebrates, the adequacy of the standards for safeguarding other ecological receptors, such as fish (e.g., eggs laid in sediment, demersal fish in direct contact with sediment) or sediment-associated wildlife, from direct exposure to contaminants is not explicitly demonstrated by the original derivation method (MacDonald et al., 2003; MWLAP, 2003). Human health risks from direct contact with contaminated sediments (e.g., during recreational and subsistence activities) are also not directly addressed by these ecologically-based standards. CSR Protocol 1 states the CSR soil standards for human health should be applied for direct sediment contact by people (BC, 2023b).
- **Inadequate Consideration of Indirect Exposure Pathways:** A significant deficiency is the absence of systematic integration of indirect exposure pathways. This particularly concerns the food chain transfer (bioaccumulation and biomagnification) of contaminants from sediment to benthic invertebrates, then to fish, and subsequently to piscivorous wildlife and humans (BC ENV, 2017b; U.S.EPA, 2002; Weisbrod et al., 2007; CSAP Society, 2015). The reliance on separate TRGs, without a clear, integrated mechanism to translate these back to protective sediment concentrations within Schedule 3.4, means this critical risk pathway is not directly managed by the numerical sediment standards themselves (MWLAP, 2003). This was also a finding of the Contaminated Sites Approved Professionals (CSAP) Society's 2015 Bioaccumulation Research Project (CSAP Society, 2015). This gap is particularly critical for persistent, bioaccumulative, and toxic (PBT) substances like mercury, polychlorinated biphenyls (PCBs), and dioxins/furans (CSAP Society, 2015).
- **Other Identified Scientific/Technical Limitations:**
 - **Limited Bioavailability Considerations:** The standards are primarily based on total bulk sediment concentrations. They do not systematically incorporate key factors known to influence contaminant bioavailability, such as sediment OC content (for organic contaminants) or AVS and simultaneously extracted metals (SEM; for certain metals) (BC, 2017a, 2024a; BC ENV, 2017b; BCWLAP, 2003; McGrath et al., 2019; Wenning et al., 2005; Allen, 2011; Parsons et al., 2007). This can lead to inaccuracies in risk prediction, potentially resulting in under- or over-protection depending on site-specific sediment geochemistry.
 - **Outdated Toxicological Data & Approaches:** The underlying PELs (CCME, 1999) and the toxicity data used for deriving adjustment factors (MacDonald et al., 2003) are now over two decades old. Substantial advancements have since occurred in ecotoxicology, including improved understanding of chronic and sublethal effects, mixture toxicity, and the development of more sensitive testing

protocols and endpoints (BC ENV, 2024; CCME, 1999DDT; Warne et al., 2018; Yan et al., 2023). Modern probabilistic approaches like Species Sensitivity Distributions (SSDs) or Benchmark Dose (BMD) modeling were not central to the original derivation (40 = BC ENV, 2024; CCME, 1999DDT).

- **Emerging Contaminants:** The current list of contaminants in Schedule 3.4 does not include many substances now recognized as emerging contaminants. These include PFAS, numerous current-use pesticides, pharmaceuticals, personal care products, 6PPD, and microplastics (CCME, 1999DDT; U.S.EPA, 2002; SETAC, 2021; Casado-Martinez et al., 2021; Owens, 2025; Okoro et al., 2011).
- **Static Nature:** BC's sediment standards have not undergone regular, comprehensive reviews and updates comparable to standards for soil and water under the CSR. This has led to a divergence from current scientific best practices and the approaches taken in other leading jurisdictions (CSAP Society, 2017; U.S. EPA, 2005). For example, the 2017 CSR Omnibus Amendments, which updated many soil and water standards, explicitly noted that the numerical limits for sediment contaminants remained unchanged at that time (BC CSR, 2017a).

C. Best Available Science for Modern Sediment Standards Development:

Developing modern sediment standards requires integrating contemporary scientific concepts, principles, and advanced methodological approaches (Chapman et al., 2002, Wenning et al., 2005, U.S.EPA, 2002; Chapman, 1989).

Modern Scientific Concepts and Principles:

- **Equilibrium Partitioning (EqP) Theory:** This theory is foundational, positing that the bioavailability and toxicity of many contaminants are primarily related to their freely dissolved concentration in sediment porewater, which is assumed to be in equilibrium with sediment-bound phases (Di Toro et al., 1991; U.S. EPA, 2003; McGrath et al., 2019). This principle underpins the United States Environmental Protection Agency's (U.S. EPA) Equilibrium Partitioning Sediment Benchmarks (ESBs) and allows for the normalization of contaminant concentrations based on key sediment properties, such as OC content for hydrophobic organic contaminants (HOCs) and AVS/SEM ratios for certain metals (Ankley et al., 1996; U.S. EPA, 2005).
- **Bioavailability Assessment:** Moving beyond basic EqP, a comprehensive bioavailability assessment considers the complex interactions of contaminants with various sediment phases (e.g., black carbon for polycyclic aromatic hydrocarbons (PAHs), iron/manganese oxides for metals). The use of advanced tools like passive sampling devices (PSDs) to directly measure bioavailable concentrations in

porewater represents a significant advancement (U.S. EPA, 2012; Wenning et al., 2005; Allen, 2011; Maruya et al., 2012).

- **Critical Body Residue (CBR) / Tissue Residue Approach:** This approach links adverse biological effects directly to the internal contaminant concentrations within organisms, rather than relying solely on external sediment concentrations. This provides a more direct measure of dose and potential risk and is particularly crucial for understanding the impacts of bioaccumulative substances (McCarty & Mackay, 1993; U.S.EPA, 2002; CSAP Society, 2015).
- **Food Web Modeling (FWM):** Quantitative FWMs are essential tools for assessing risks to wildlife and human consumers. These models simulate the transfer and potential biomagnification of contaminants through multiple trophic levels of an aquatic ecosystem, starting from concentrations in abiotic compartments like sediment and water (Greenfield et al., 2014; Arnot & Gobas, 2004; 193; von Stackelberg et al., 2017)
- **Weight-of-Evidence (WoE) / Sediment Quality Triad (SQT):** The SQT, pioneered by Chapman (1990), and broader WoE frameworks integrate multiple lines of evidence—typically including sediment chemistry, laboratory toxicity tests, and in-situ benthic community assessments (plus bioaccumulation data in modern applications)—to provide a more holistic and ecologically relevant assessment of sediment quality than relying on chemical criteria alone (Chapman et al., 1997; Wenning et al., 2005; REFs: Chapman et al., 2002; Manfra et al., 2021).
- **Species Sensitivity Distributions (SSDs):** SSDs are probabilistic models that describe the statistical distribution of toxicity thresholds across a diverse range of species. They allow for the derivation of protective contaminant concentrations, such as the Hazardous Concentration for 5% of species (HC_5), based on a pre-defined level of ecological protection (Posthuma et al., 2002; Warne et al., 2018; U.S. EPA, 2016; BC, 2025).
- **Adverse Outcome Pathways (AOPs):** AOPs provide a structured framework for understanding the linkage between a molecular initiating event caused by a stressor and an adverse outcome relevant to risk assessment (e.g., at the individual or population level). While still an evolving field for direct standard derivation, AOPs can help in understanding mechanisms of toxicity, selecting relevant toxicological endpoints, and identifying data gaps (Ankley et al., 2010).
- **Sediment-Ecosystem Regional Assessment (SEcoRA):** Beyond traditional chemical and toxicological assessments, a modern framework should also consider the broader conceptual framework provided by the SEcoRA. This approach emphasizes understanding the dynamic interactions of sediment status defined by its quality (composition, grain size, organic content, nutrients, contaminants, pathogens), quantity (amount lost, generated, transported), transport dynamics, and location, on diverse ecological endpoints at the landscape or watershed scale.

This holistic view recognizes sediments' multifaceted roles as critical habitats, valuable resources, potential stressors, and important indicators of ecosystem health, moving beyond a sole focus on contamination to integrate the broader range of ecosystem services they provide (Apitz, 2012).

Advanced Techniques and Methodological Approaches:

- **Advanced Toxicity Testing:** Modern approaches emphasize the use of chronic and sublethal endpoints (e.g., effects on growth, reproduction, development), multi-species tests, and in-situ bioassays to provide more ecologically relevant data (U.S. EPA, 1994; U.S. EPA, 1999; U.S. EPA, 2015). Development of standardized tests for emerging contaminants and unique materials like sediment-associated nanoparticles is ongoing.
- **Bioavailability Measurement Tools:** Routine use of OC normalization for HOCs and AVS/SEM analysis for relevant metals is becoming standard practice (U.S. EPA, 2005; McGrath et al., 2019; Wenning et al., 2005; Allen, 2011; Greenberg et al., 2014). Advanced tools like passive sampling devices (e.g., Solid Phase Microextraction (SPME), Polyethylene (PE) strips, Diffusive Gradients in Thin Films) for measuring freely dissolved concentrations (C_{free}) in porewater offer more direct measures of the bioavailable fraction (U.S. EPA, 2012).
- **Bioaccumulation Assessment:** This includes standardized laboratory bioaccumulation tests with relevant benthic species (e.g., ASTM, 2017), the compilation and critical evaluation of Biota-Sediment Accumulation Factors (BSAFs), and the application of dynamic or steady-state FWMs (U.S. EPA, 2000; U.S. EPA, 2002; Weisbrod et al., 2007; CSAP Society, 2015; Greenfield et al., 2014).
- **Benthic Community Assessment:** Beyond basic diversity indices, advanced assessments incorporate multivariate statistical analyses to discern relationships between community structure and multiple stressors, and include functional endpoints such as secondary production where feasible (Chapman et al., 2002; Wenning et al., 2005).
- **Environmental DNA (eDNA):** The use of eDNA analysis is an emerging tool for assessing biodiversity and the presence/absence of sensitive or invasive species in aquatic environments. This non-invasive method can complement traditional benthic community assessments by providing broader taxonomic coverage and detecting species at low densities or in difficult-to-sample habitats (REF). While not yet a primary driver for numerical standards, eDNA offers promise for future ecological risk assessments and monitoring programs.
- **Probabilistic Risk Assessment & Modeling:** The application of SSDs for guideline derivation is a key example (Warne et al., 2018; U.S. EPA, 2016). Monte Carlo simulations can be used to quantitatively incorporate uncertainty into risk

assessments, and Bayesian statistical approaches (e.g., Bayesian Networks or BN) offer powerful methods for integrating diverse datasets and updating assessments as new information becomes available (ADD Landis; Warren-Hicks & Moore, 1998; Warne et al., 2018; U.S. EPA, 2016).

- **"Omics" Technologies:** Fields such as genomics, transcriptomics, proteomics, and metabolomics are emerging as powerful tools for understanding the molecular mechanisms of toxicity and developing sensitive biomarkers of exposure and effect (Ankley et al., 2006). While their application in routine sediment guideline derivation is still in developmental stages, they hold promise for future refinements (REF).

Potential for Incorporation into a Modernized BC Framework:

A modernized BC framework should aim to develop a hybrid approach, strategically leveraging the strengths of various contemporary scientific concepts and techniques. This includes:

- Developing benthic-protective sediment standards (SedS-direct) using robust methodologies like SSDs, supplemented by EqP principles and specific bioavailability adjustments (e.g., OC normalization, AVS/SEM considerations where appropriate) (McGrath et al., 2019; U.S. EPA, 2002; CCME, 2025; CSAP Society, 2015; BC ENV, 2024; Warne et al., 2018).
- Developing distinct food pathway and bioaccumulation-protective sediment standards (SedS-food) by linking protective tissue residue levels in relevant wildlife and human food sources back to corresponding sediment concentrations. This translation would be achieved using appropriately validated BSAFs or FWMs (CCME, 2025; CSAP Society, 2015; CalEPA, 2017; Greenfield et al., 2014).
- Implementing a tiered assessment framework. Initial screening against the generic (non-site-specific) sediment standards (SedSs) would be followed by more comprehensive WoE or Bayesian Network - Relative Risk Model (BN-RRM) framework (integrating sediment chemistry, potential toxicity, exposure and toxicity modifying factors, benthic community analysis, and bioaccumulation information) for sites that exceed initial screening thresholds, present complex scenarios, and/or where default assumption made in the development of generic numerical sediment standards are not relevant to site conditions (Chapman et al., 2002; Ontario MECP, 2008; Greenfield et al., 2014).
- Systematically incorporating bioavailability adjustments into the application of guidelines. This includes standard OC normalization and AVS/SEM assessments, with provisions for using advanced tools like PSDs in higher-tier, site-specific evaluations (McGrath et al., 2019; Allen, 2011; Greenberg et al., 2014).
- Expanding the list of regulated contaminants to proactively include standards or robust assessment strategies for emerging substances of concern relevant to BC environments (REF: 11; CCME, 2025; SETAC, 2021).

- Establishing a regular and transparent review cycle for updating the sediment standards and the underlying framework to ensure they remain aligned with the best available science and evolving environmental challenges (CSAP Society, 2017; Landis et al., 2016; U.S. EPA, 2005).

III. Jurisdictional Scan: Sediment Quality Screening Values

A. Methodology for Jurisdictional Review:

The jurisdictional scan involved a review of publicly available regulatory documents, technical guidance, and scientific literature from selected Canadian federal and provincial bodies, United States federal and state agencies, the European Union, Australia/New Zealand, and key Asian countries. The criteria for selecting jurisdictions included the presence of established or modern sediment quality management frameworks, relevance to BC's environmental context (e.g., similar ecosystems or contaminant issues), and innovative approaches to guideline derivation or application. The scope focused on how different agencies derive sediment quality screening values/guidelines, address bioavailability and bioaccumulation, and integrate these into regulatory decision-making.

B. Overview of Approaches in Other Government Agencies:

Canadian Jurisdictions (Provincial and Federal):

- **CCME:** Provides national baseline guidance with Interim Sediment Quality Guidelines (ISQGs) and Probable Effect Levels (PELs) derived from empirical co-occurrence data, primarily focused on benthic invertebrate protection. The CCME PELs were adopted as preliminary benchmarks in the 2003 BC SedQC development process. CCME also has protocols for deriving TRGs for wildlife. The derivation methodology for SQGs, focusing on direct benthic toxicity, was outlined in a 1995 protocol (CCME, 1995) and further detailed in later documents.
 - **Primary Website:** [Canadian Environmental Quality Guidelines \(CEQGs\)](#)
 - **Key Documents:**
 - CCME. (1999). Canadian environmental quality guidelines. (This is the overarching publication for the values, including the 1999 PELs). [CCME, 2025a]
 - CCME. (1995). Protocol for the Derivation of Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. (This document outlines the original empirical methodology). [CCME, 1995]
 - CCME. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life - DDT, DDE, and DDD. (This is a specific example of a guideline document following the protocol). [Canadian Council of Ministers of the Environment (CCME), 1999DDT]
- **ECCC (Environment and Climate Change Canada):** Develops Federal Environmental Quality Guidelines (FEQGs) for priority substances, sometimes

including sediment, often to fill gaps or update CCME values.

- **Primary Website:** [Federal Environmental Quality Guidelines \(FEQGs\)](#)
- **Key Documents:**
 - ECCC. *Federal Environmental Quality Guidelines (FEQGs)*. (This is the main landing page explaining the purpose of FEQGs. Includes 40 water, 17 sediment guidelines, 11 fish tissue, and other guidelines). [ECCC, 2024a]
 - ECCC. *Federal environmental quality guidelines - Lead*. (This is an example of a specific FEQG that includes sediment values). [ECCC, 2024 Lead]
- **Ontario MECP (Ministry of the Environment, Conservation and Parks):**

Employs Provincial Sediment Quality Guidelines with three tiers: No Effect Level (NEL), Lowest Effect Level (LEL), and Severe Effect Level (SEL), based on empirical data and used within a WoE framework. The NEL aims for no toxic effects and no food chain biomagnification, while LEL signifies marginal pollution and SEL indicates heavy contamination requiring management.

 - **Primary Website:** [Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario](#)
 - **Key Documents:**
 - Ontario Ministry of the Environment, Conservation and Parks (MECP). (2008). *Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario*. [Ontario MECP, 2008]
 - Ontario Ministry of Environment and Energy (MOEE). (1993). *Guidelines for the protection and management of aquatic sediment quality in Ontario*. (The foundational document for the PSQGs). [Ontario MOEE, 1993]
- **Quebec MELCC (Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parc):** Uses a five-tiered system (Rare Effect Level - REL, Occasional Effect Level - OEL, Threshold Effect Level - TEL, Probable Effect Level - PEL, Frequent Effect Level - FEL) derived from CCME's database to support sediment management decisions, including dredging. These criteria are used as screening tools, often with natural background levels and toxicity testing (Environment Canada & Ministère du Développement durable, Environnement et des Parcs du Québec, 2008).
 - **Primary Website:** [Sediment Quality Criteria](#)
 - **Key Documents:**
 - Environment Canada and Ministère du Développement durable, de l'Environnement et des Parcs du Québec. (2007). *Criteria for the Assessment of Sediment Quality in Quebec and Application Frameworks: Prevention, Dredging and Remediation*. [Environment Canada & MELCC, 2008]
- **Atlantic RBCA (Risk-Based Corrective Action):** Provides Tier 1 Ecological Screening Levels (ESLs) for petroleum hydrocarbons (PHCs), incorporating EqP

and OC normalization. Other contaminants often reference CCME PELs. This framework favors realistic effect thresholds (PEL-level) for Tier 1 screening. Rationale and guidance on the Atlantic RBCA framework including sediment standards is provided in Atlantic RBCA (2023).

- **Primary Website:** [Atlantic RBCA](#)
- **Key Documents:**
 - [Atlantic PIRI. \(2012\).](#) *Ecological Screening Protocol for Petroleum Impacted Sites in Atlantic Canada: Scientific Rationale.* [Atlantic PIRI, 2012]
 - [Atlantic PIRI. \(2023\).](#) *Atlantic RBCA Environmental Quality Standards Rationale and Guidance Document.* [Atlantic PIRI, 2023, 125]
- **Alberta AEP (Ministry of Environment and Protected Areas):** Primarily relies on CCME SQGs for sediment, within a broader tiered framework for contaminated sites.
 - **Primary Website:** [Alberta Tier 1 soil and groundwater remediation guidelines](#)
 - **Key Documents:**
 - Alberta Environment and Parks. *Environmental Quality Guidelines for Alberta Surface Waters.* [Alberta Environment and Parks (AEP), 2018]
 - Regional Aquatics Monitoring Program (RAMP). *Water and Sediment Quality Guidelines.* (This document explicitly states the reliance on CCME guidelines for the region). [Source: 171]
 - Alberta Energy Regulator. *Manual 021: Contamination Management.* (This provides a broader regulatory context). [Alberta Energy Regulator (AER), 2025]

Selected International Jurisdictions:

- **U.S. EPA:**
 - **Equilibrium Partitioning Sediment Benchmarks (ESBs):** Mechanistically derived benchmarks for non-ionic organics (OC-normalized) and metals (AVS/SEM-based), focused on porewater exposure and direct toxicity protection. ESBs derive sediment criteria from water quality benchmarks by accounting for bioavailability. The approach does not explicitly incorporate bioaccumulation in its derivation.
 - **National Contingency Plan (NCP)/Superfund:** Employs a risk-based approach for site cleanup, not generic SQGs, but ESBs and other screening values (e.g., Effects Range Low / Effects Range Median (ERLs/ERMs) from the National Oceanic and Atmospheric Association (NOAA), TELs/PELs) are used in initial assessments.
 - **Great Lakes Water Quality Guidance Agreement (GLWQA):** Focuses on Bioaccumulative Chemicals of Concern (BCCs), with methodologies for deriving

criteria protective of aquatic life, human health, and wildlife, incorporating bioaccumulation factors (BAFs)/BSAFs.

- **Primary Websites:**

- [Equilibrium Partitioning Sediment Benchmarks \(ESBs\)](#) (The principles page often links to technical resources like ESBs)
- [Superfund: Contaminated Sediments](#)
- [Great Lakes Water Quality Guidance \(GLWQI\)](#)

- **Key Documents:**

- **ESBs:** U.S. EPA. (2003). *Procedures for the derivation of equilibrium partitioning sediment benchmarks (ESBs) for the protection of benthic organisms: PAH mixtures*. [U.S. EPA, 2003, U.S. EPA, 2008]
- **Superfund/NCP:** U.S. EPA. *Sediment Risk Management Principles. & Contaminated Sediments: Control, Treatment, and Remediation*. [U.S. EPA, 2017, U.S. EPA, 2005]
- **GLWQI:** Code of Federal Regulations. *40 CFR Part 132 -- Water Quality Guidance for the Great Lakes System*. [U.S. EPA, 1995, 2002]

- **Interstate Technology & Regulatory Council: Blah blah blah**

- **Primary Website:** <https://pfas-1.itrcweb.org/>

- **Key Documents:**

- **Washington State (Department of Ecology):** The Sediment Management Standards (SMS; WAC 173-204) provide a comprehensive regulatory framework. This includes numeric chemical Sediment Quality Standards (SQSs) ("no adverse effects") and Cleanup Screening Levels (CSL) ("minor adverse effects"). Biological testing criteria (toxicity and benthic infauna) are integrated, and human health protection goals are included. OC normalization is used for some organics.

- **Primary Website:** [Sediment Cleanups](#)

- **Key Documents:**

- Washington Administrative Code. *Chapter 173-204 WAC: Sediment Management Standards*. [Washington State DEP, 2013a]
- Washington State Department of Ecology. (2013). *Sediment Cleanup Users Manual II (SCUM II): Guidance for Implementing the Sediment Management Standards*. [Washington State DoE, 2013b]

- **California SWRCB/OEHHA (State Water Resources Control Board/Office of Environmental Health Hazard Assessment):** Employs narrative Sediment Quality Objectives (SQOs) implemented via a weight-of-evidence Triad approach (chemistry, toxicity, benthic community) for aquatic life protection. Human health protection is linked to fish tissue contaminant goals (OEHHA Advisory Tissue Levels - ATLS) and bioaccumulation modeling (SWRCB, 2018).

- **Primary Websites:**

- [OEHHA Fish Advisories and Guidelines](#)
 - [SWRCB Sediment Quality Objectives \(SQOs\)](#)
- **Key Documents:**
 - CalEPA. (2017). *Fish Contaminant Goals and Advisory Tissue Levels for Evaluating Methylmercury...* [CalEPA, 2017]
 - Yee, D. et al. (2014). *A Tiered Assessment Framework to Evaluate Human Health Risk of Contaminated Sediment*. (This research paper describes the SQO framework). [Greenfield et al., 2014]
- **Florida DEP (Department of Environmental Protection):** Uses Sediment Quality Assessment Guidelines (SQAGs) based on TEL/PEL concepts (Minimal, Possible, Probable Effects Ranges). Includes geochemical normalization for metals and specific bioaccumulation-based SQAGs for wildlife/human health.
 - **Primary Website:** [Sediment Guidelines](#)
 - **Key Documents:**
 - Florida DEP. (1994). Approach to the Assessment of Sediment Quality in Florida Coastal Waters. [Florida DEP, 1994]
 - Florida DEP. (2003). *Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for Florida Inland Waters*. [Florida DEP, 2003]
- **European Union WFD/SedNet (Water Framework Directive/Sediment Network):** No European Union (EU)-wide numerical sediment standards. The WFD requires "good ecological and chemical status," with Member States developing national approaches. SedNet promotes integrated, risk-based sediment management using WoE. Focus is often on source control and River Basin Management Plans (EU, 2000).
 - **Primary Websites:**
 - [EU Water Framework Directive](#)
 - [SedNet \(The European Sediment Network\)](#)
 - **Key Documents:**
 - European Parliament. (2000). *Directive 2000/60/EC (Water Framework Directive)*. [European Parliament, 2000]
 - SedNet. (2004). *Sediment management in the context of the EU Water Framework Directive*. [SedNet, 2004]
 - European Commission. (2022). *Integrated sediment management Guidelines and good practices in the context of the Water Framework Directive*. [European Commission, 2022]
- **Australia & New Zealand Governments (ANZG):** Provides Default Guideline Values (DGVs, often TEL-based) and Guideline Values-High (GV-high, often

PEL-based) (ANZG, 2019). Emphasizes WoE for exceedances and OC normalization (0.2-10%) for HOCs. SSDs are increasingly used for derivation.

- **Primary Website:** [Australian and New Zealand Guidelines for Fresh and Marine Water Quality](#)
- **Key Documents:**
 - Batley et al. (2014). Technical rationale for changes to the method for deriving Australian and New Zealand water quality guideline values for toxicants.
 - ANZG. (2018). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. (Main portal). [ANZG, 2018a]
 - Warne, M. St.J. et al. (2018). *Revised method for deriving Australian and New Zealand water quality guideline values for toxicants*. (Describes the SSD methodology). [Warne et al., 2018]
 - ANZG. (2018). *Toxicant default guideline values for sediment quality*. (The specific page with the values). [ANZG, 2018b]
- **China:** Has a national marine sediment standard (GB 18668-2002) with three quality classes. The Ministry of Ecology and Environment (MEE) has technical guidelines for deriving Water Quality Criteria (HJ 831-2017) using SSDs, excluding bioaccumulative chemicals from this specific method.
 - **Primary Website:** [Ministry of Ecology and Environment of the People's Republic of China](#)
 - **Key Documents:**
 - *Marine Sediment Quality standard (GB 18668-2002)*. (This is the national standard, often cited in research papers). [Yang et al., 2022]
 - Ma, Y. et al. (2023). *Chinese Technical Guideline for Deriving Water Quality Criteria for Protection of Freshwater Organisms*. (Describes the SSD-based methodology for water, HJ 831-2017). [Yan et al., 2023]
- **Japan MOE (Ministry of the Environment):** Focuses on water and effluent standards. Sediment management is often linked to controlling specific pollutants (e.g., mercury, dioxins) based on health risks or specific incidents, rather than a broad suite of numerical screening values.
 - **Primary Website:** [Ministry of the Environment, Government of Japan](#)
 - **Key Documents:**
 - MOE. *Conservation of the Water Environment*. (This provides an overview of their water quality standards). [MOE Japan, 1997]
 - MOE. *National Effluent Standards*. (Shows their focus on controlling discharges). [Japan MOE, 2015]
 - U.S. Army Engineer Waterways Experiment Station. (1987). *Management of Bottom Sediments Containing Toxic Substances: Proceedings of the*

U.S./Japan Experts Meeting. (Shows historical engagement on the topic).
[U.S. Army Engineers, 1985, 1987]

C. Innovative or Noteworthy Approaches and Best Practices:

- **WoE Integration:** Frameworks and guidance in ANZG, Ontario, Washington State, California, and EU strongly advocate or mandate the use of WoE, combining chemistry, toxicity, and ecological data for more robust assessments.
- **Explicit Bioavailability Adjustments:** U.S. EPA ESBs (OC, AVS/SEM), ANZG (OC normalization), Washington SMS (OC normalization), and Atlantic RBCA (OC normalization for PHCs) explicitly incorporate bioavailability. The use of passive sampling methods (PSMs) for Cfree measurement is an emerging bioavailability assessment tool.
- **Direct Linkage to Bioaccumulation and Human/Wildlife Health:** California's SQO framework directly links sediment quality to fish tissue objectives for human health. The Great Lakes guidance and TRG approaches (e.g., CCME) provide mechanisms to protect wildlife.
- **SSDs:** Use of SSDs for deriving protective concentrations (e.g., ANZG, China's WQC guidance, increasingly in CCME/FEQGs) offers a more statistically robust and transparent method than older empirical percentile approaches.
- **Tiered Assessment Frameworks:** Many jurisdictions (e.g., ANZG, Atlantic RBCA, Ontario, Washington) use a tiered approach, starting with screening against generic guidelines and progressing to more detailed site-specific assessments if initial thresholds are exceeded.
- **Adaptive Management and Regular Review:** Some frameworks emphasize the need for periodic review and updates to guidelines to reflect new science.

D. Synthesis and Key Learnings for BC:

The current sediment standards, based on adjusted 1999 CCME PELs, are outdated compared to leading international frameworks. There is a strong global trend towards incorporating bioavailability adjustments, using WoE approaches, and explicitly protecting against bioaccumulation and food web transfer risks. No single jurisdiction offers a perfect off-the-shelf model for BC, suggesting a hybrid approach is needed, adopting best-practice elements from various frameworks. Key elements for BC to consider include: adopting a dual-guideline system (benthic and bioaccumulation protection), mandating bioavailability adjustments, formalizing WoE, expanding contaminant coverage, and establishing a regular update cycle. The move towards more sophisticated assessment will require enhanced technical guidance and capacity building in BC.

Table 1. Comparative Matrix of Sediment Quality Frameworks (Summary)

Feature	BC CSR Schedule 3.4 (Current)	U.S. EPA ESBs	U.S. EPA Superfund/NCP	ANZG 2019	Washington State SMS	California OEHHA/SQO
Derivation Basis	Empirical (PEL-based)	Mechanistic (EqP)	Risk-Based	Empirical (TEL/PEL-based)	Mixed (Empirical, WoE)	Risk-Based (Tissue) / WoE
Aquatic Settings	FW, Mar, Est	FW, Mar	Site-Specific	FW, Mar	FW, Mar, Est	Mar, Est
Bioavailability	Limited (Active Zone)	OC norm, AVS/SEM	Site-Specific	OC norm (0.2-10%)	OC norm, AVS/SEM	Food Web Model considers
Bioaccumulation/Food Web	None Explicitly	None in Derivation	Risk Assessment	WoE includes Bioacc.	Explicit (WoE, TRG)	Explicit (FWM, HHRA link)
Human Health Path	Not Protective	Not Addressed	HHRA	WoE considers HH risk	HH Risk Addressed	Explicit (Fish Consumption)
Conservatism	Medium	Medium (direct tox)	Variable	Medium (DGV)	Medium (SMS/CSL)	Variable (ATL/FCG)
Update Mechanism	May be reviewed every 5 years	Ad hoc	Site-Specific	Ongoing Revision	Periodic Updates	Periodic Updates

Abbreviations: FW: Freshwater; Mar: Marine; Est: Estuarine; EqP: Equilibrium Partitioning; OC norm: Organic Carbon normalization; AVS/SEM: Acid Volatile Sulfide/Simultaneously Extracted Metals; WoE: Weight-of-Evidence; HH: Human Health; HHRA: Human Health Risk Assessment; TRG: Tissue Residue Guideline; FWM: Food Web Model; TEL: Threshold Effect Level; REL: Rare Effect Level; CSR: Contaminated Sites Regulation; PEL: Probable Effect Level; DGV: Default Guideline Value; SMS: Sediment Management Standard; CSL: Cleanup Screening Level; ATL: Advisory Tissue Level; FCG: Fish Contaminant Goal

IV. Community and Stakeholder Engagement Insights

(Information in this section is based on planned activities as results are not yet available.)

A. Engagement Strategy and Objectives:

A comprehensive engagement strategy is planned to ensure that the modernization of BC's sediment standards is informed by a diverse range of perspectives, knowledge, and practical considerations. The primary objectives of this engagement are:

- To inform stakeholders and First Nations about the initiative to update sediment standards.
- To gather input on the scientific and technical aspects of the proposed framework.
- To understand potential implementation challenges and opportunities from various user perspectives (e.g., regulators, consultants, industry, First Nations, non-profit organizations).
- To incorporate Traditional Ecological Knowledge where relevant and appropriate.
- To build transparency and support for the updated standards.

The strategy will involve broad public consultation as well as targeted engagement with technical experts, Indigenous communities, industry sectors, and environmental non-governmental organizations.

B. Online Survey (Open: May 31 - July 31, 2025):

Survey Design, Target Audience, and Dissemination:

An online survey questionnaire was developed to solicit input from the general public, interested organizations, and professionals involved in contaminated sites management. Key themes for the survey included: perceived importance of sediment quality, concerns about current sediment contamination issues, priorities for protection (e.g., ecological health, human health, specific water uses), opinions on the level of desired protection, and feedback on the general direction of modernizing standards (e.g., incorporating bioaccumulation, bioavailability). The target audience was broad, including BC residents, First Nations members, environmental consultants, industry representatives, academics, and members of environmental organizations.

Dissemination occurred through government websites, email distribution lists to known stakeholders (e.g., Site Remediation News, CSAP Society, industry associations, non-profit organizations, First Nations organizations), and social media. The survey was designed to be accessible and understandable to a non-technical audience where appropriate, with sections for more detailed technical input.

Anticipated Summary of Key Findings and Themes:

It is anticipated that the online survey will yield insights into public and stakeholder priorities concerning sediment standards. Expected findings may include:

- Levels of concern regarding sediment contamination in different BC regions or water body types.
- Prioritization of protection goals (e.g., protection of endangered species, safe fish consumption, benthic ecosystem health).
- Support for incorporating more advanced scientific principles into the standards.
- Potential concerns about the economic or practical implications of stricter standards.
- Suggestions for specific contaminants or issues to be addressed.

The survey results will be analyzed to identify common themes, areas of consensus, and points of divergence among different stakeholder groups. This information will help inform the refinement of the proposed framework and identify areas requiring further communication or consideration. (Survey results are pending.)

C. Canadian Ecotoxicity Workshop (CEW) - Science and Standards Technical Advisory Committee (SSTAC) Session October 7, 2025:

Session Overview and Objectives:

A dedicated session or series of activities (presentations, workshops, poster session) is planned within the Science and Standards Technical Advisory Committee (SSTAC) at the Canadian Ecotoxicity Workshop (CEW). The purpose of this engagement is to solicit in-depth scientific and technical feedback on the preliminary proposed framework for modernized sediment standards from Canadian and international ecotoxicology experts, risk assessors, and regulators. Participants will primarily be scientific and technical experts attending the CEW.

Summary of Key Discussions from Presentations, Workshops, and Poster Engagement:

It is planned that presentations will cover the rationale for updating BC's sediment standards, the findings of the preliminary scientific research and jurisdictional scan, and the interim proposed framework. Workshops may focus on specific technical challenges, such as methodologies for deriving bioaccumulation-protective standards, practical application of bioavailability adjustments, or approaches for emerging contaminants. A poster presentation will provide an overview of the project for broader CEW attendees. Key scientific/technical topics planned for discussion include:

- Appropriateness of proposed derivation methodologies (e.g., SSDs, FWMs).
- Selection and justification of protection goals (e.g., HC₅).
- Technical feasibility of implementing bioavailability adjustments.

- Data requirements and uncertainties associated with the proposed framework.
- Approaches for specific contaminant classes (e.g., PFAS, microplastics).

Expert opinions will be sought on scientific defensibility, practicality, and potential unintended consequences of the proposed changes. (SSTAC session outcomes are pending.)

Consolidated Key Feedback, Insights, and Recommendations from SSTAC:

It is expected that the SSTAC engagement will yield:

- Overarching themes regarding the scientific validity and robustness of the proposed framework.
- Specific scientific advice on methodologies, data interpretation, and uncertainty analysis.
- Critical insights into potential challenges or limitations.
- Actionable recommendations for refining the proposed framework and its implementation.
- Identification of key knowledge gaps requiring further research.
- Points of scientific consensus or significant divergence among experts.

This feedback will be crucial for ensuring the scientific credibility of the modernized standards. (SSTAC feedback is pending.)

D. Synthesis of All Community and Stakeholder Engagement Feedback:

A full synthesis of engagement feedback is pending the completion of these activities. Once available, the collective input from the online survey, the SSTAC/CEW session, and any other targeted consultations (e.g., with First Nations, specific industry sectors) will be systematically compiled, analyzed, and summarized. This synthesis will identify key themes, areas of broad support, significant concerns, and specific suggestions. The project team will then evaluate how this feedback can be integrated to refine the proposed framework for modernized sediment standards, improve implementation strategies, and enhance communication. A "What We Heard" report may be produced to document the engagement process and outcomes.

V. Proposed Framework for Modernized Sediment Standards

The modernization of BC sediment standards requires a comprehensive and robust scientific framework. This proposed framework draws upon international best practices and the latest scientific understanding to address the limitations of the current standards, particularly concerning bioavailability, bioaccumulation, food web transfer, and emerging contaminants. The goal is to establish guidelines that are protective of

benthic ecosystems, wildlife, and human health across freshwater, marine, and estuarine environments in BC.

A. Guiding Principles for the New Framework

The development and implementation of new sediment standards for BC will be guided by the following core principles:

- **Protection of Ecological Health:** Standards will be fundamentally set to protect the health, diversity, and ecological function of benthic ecosystems and all sediment-associated aquatic life.
- **Protection of Wildlife and Human Health:** The framework will explicitly incorporate mechanisms to safeguard wildlife and human consumers from risks associated with the bioaccumulation and trophic transfer of contaminants from sediment. Direct human contact risks will also be considered where relevant.
- **Holistic Sediment Functionality:** The framework will recognize and manage sediments not only as potential sources of contamination but also as dynamic components integral to sustaining a wide range of ecosystem services, including habitat provision, nutrient cycling, and the long-term health of aquatic ecosystems (Apitz, 2012). This broader perspective ensures that management decisions consider both positive and negative impacts of sediment status.
- **Scientifically Defensible:** Standards derived using the new framework will incorporate best available scientific knowledge, employing robust and transparent methodologies such as SSDs, EqP modeling, and FWMs.
- **Bioavailability-Informed Assessment:** The influence of sediment physicochemical properties (e.g., OC content, acid volatile sulfides) on contaminant bioavailability will be systematically incorporated into the derivation methods and application of the standards.
- **Comprehensive Contaminant Coverage:** The framework will address legacy contaminants and prioritize the timely inclusion of relevant emerging contaminants of concern, such as PFAS and current-use pesticides.
- **Tiered and Flexible Application:** A tiered assessment approach will be central, allowing for efficient screening using the numerical guidelines at initial stages (Tier 1), while providing clear pathways for more detailed, site-specific investigations (Tier 2/3) that incorporate multiple lines of evidence (Weight-of-Evidence).
- **Practical and Implementable:** While ensuring robust protection, the framework will strive for practicality in terms of sampling requirements, analytical capabilities, and remediation considerations, supported by clear guidance.
- **Transparent and Clear Communication:** The scientific basis, derivation methods, application protocols, and inherent limitations of the standards will be clearly documented and communicated to all stakeholders.
- **Adaptive Management:** A formal mechanism for regular review and updates (e.g.,

every 5-10 years) will be established to ensure the standards remain current with evolving scientific understanding and environmental challenges (Landis et al., 2016; CSAP Society, 2015? Check if this makes sense; Probably add others too).

B. Key Components and Structure of the Proposed Framework

The proposed framework for modernized BC sediment standards will be structured around several key components:

1. **Dual Standard Approach (Matrix):** To address distinct protection goals, a dual standard system is proposed for contaminants, particularly those that are PBTs):
 - **Sediment Standards for Direct Protection (SedS-direct):** This standard will be primarily designed to protect ecological organisms and people from adverse effects associated with direct exposure to contaminated sediment. Derivation will prioritize methods like SSDs based on chronic benthic toxicity data, incorporating bioavailability adjustments (e.g., normalization to OC for organic contaminants, AVS/SEM considerations for metals).
 - Human Health Protection: $\text{SedS-direct}_{\text{HH}}$
 - Ecological Health Protection: $\text{SedS-direct}_{\text{ECO}}$
 - **Sediment Standard for Bioaccumulation Protection (SedS-food):** This standard will be specifically designed to protect higher-trophic-level organisms, including piscivorous wildlife and human consumers of aquatic foods, from adverse effects resulting from the bioaccumulation and biomagnification of contaminants through the food web. Derivation will involve linking protective TRGs or human health risk-based tissue concentrations back to sediment concentrations using scientifically validated BSAFs or FWMs. For site assessment and management, the more stringent (i.e., lower concentration) of the **SedS-direct and SedS-food** for a given contaminant will typically serve as the primary screening benchmark to trigger further investigation or action.
 - Human Health Protection: $\text{SedS-food}_{\text{HH}}$
 - Ecological Health Protection: $\text{SedS-food}_{\text{ECO}}$
2. **Tiered Assessment Approach (Protocol 2):** A tiered approach to sediment quality assessment will be implemented to ensure efficient use of resources while maintaining protective outcomes:
 - **Tier 1: Initial Screening:** Site-specific sediment chemistry data (incorporating standard bioavailability adjustments) will be compared against the **SedS-direct and SedS-food** values. Sites where all contaminant concentrations are below these initial screening levels would generally be considered of low concern, potentially requiring no further action or only baseline monitoring.
 - **Tier 2: Site-Specific Investigation / Weight-of-Evidence (WoE):** If Tier 1

screening levels are exceeded, a more detailed site-specific investigation will be triggered. This tier will involve the collection and integration of **specific lines of evidence (LOE)** may be evaluated within a structured WoE framework or **Bayesian Network Relative Risk Model Approach (to be determined)**. This approach is consistent with the comprehensive understanding of 'sediment status' (quality, quantity, location, transport) advocated by frameworks like SEcoRA, allowing for a more complete picture of impacts on diverse ecological endpoints (Apitz, 2012). Relevant LOEs may include:

- Advanced, site-specific bioavailability assessments (e.g., use of PSDs, refined partitioning studies).
 - Sediment toxicity testing using appropriate acute and chronic bioassays with relevant species.
 - Benthic invertebrate community assessments (e.g., analyzing species diversity, abundance, presence of sensitive taxa, community structure indices, eDNA).
 - Measurement of contaminant concentrations in the tissues of local biota (invertebrates, fish, shellfish).
 - Application of site-specific or refined food web models and BSAF determinations.
- **Tier 3: Screening Level Risk Assessment and Management Decisions:** If Tier 2 screening levels are exceeded, a more detailed site-specific investigation. This tier will involve the collection and integration of **multiple LOEs within a structured WoE framework or BN-RRM (to be determined)**. This approach is consistent with the comprehensive understanding of 'sediment status' (quality, quantity, location, transport) advocated by frameworks like SEcoRA, allowing for a more complete picture of impacts on diverse ecological endpoints (Apitz, 2012). Relevant LOEs may include:
- Advanced, site-specific bioavailability assessments (e.g., use of PSDs, refined partitioning studies).
 - Sediment toxicity testing using appropriate acute and chronic bioassays with relevant species.
 - Benthic invertebrate community assessments (e.g., analyzing species diversity, abundance, presence of sensitive taxa, community structure indices, eDNA).
 - Measurement of contaminant concentrations in the tissues of local biota (invertebrates, fish, shellfish).
 - Application of site-specific or refined FWMs and BSAF determinations.
- **Tier 4: Detailed Risk Assessment and Management Decisions:** Based on the integrated findings from the Tier 2/3 WoE assessment, a comprehensive ecological and human health risk assessment may be conducted to quantify risks, delineate the extent of contamination requiring management, and inform

the selection of appropriate risk management or remedial actions.

3. **Systematic Incorporation of Bioavailability:** The framework will mandate the systematic consideration of contaminant bioavailability:
 - **Standard Normalization:** For Tier 1 screening, standardized procedures for normalizing concentrations of non-ionic organic contaminants to sediment OC content (e.g., within a Total OC range of 0.2% to 10%) will be required. For relevant cationic metals in anoxic sediments, the AVS/SEM paradigm will be applied. Clear guidance on site-specific data collection (e.g., Total OC, AVS, SEM) will be provided.
 - **Advanced Bioavailability Tools:** For Tier 2/3 assessments, the framework will encourage and provide guidance on the use of more advanced bioavailability assessment tools, such as PSDs for measuring Cfree, and refined bioavailability models.
4. **Expanded and Prioritized Contaminant List:** The list of contaminants with sediment standards in Schedule 3.4 will be expanded to include substances of current and emerging concern in BC. This will involve:
 - Reviewing and updating standards for currently listed legacy contaminants (metals, PAHs, PCBs, select pesticides) using the best available science and derivation methods outlined.
 - Developing new guidelines for prioritized emerging contaminants such as PFAS, organotins (e.g., tributyltin or TBT), dioxins/furans (as toxic equivalents or TEQs), and relevant current-use pesticides.
 - Establishing a strategy for addressing microplastics, which may initially involve narrative standards, monitoring triggers, and a commitment to developing numerical thresholds as the science matures. Contaminant prioritization will consider detection frequency in BC, toxicity, persistence, and bioaccumulation potential.
5. **Clear Linkage to Site Use and Protection Goals:** The framework will refine how site-specific uses and protection goals are considered. This likely involves:
 - Revising the current "Sensitive" versus "Typical" use categories to be more explicitly linked to specific ecological receptors (e.g., critical wildlife habitats, salmon spawning areas), human uses (e.g., shellfish harvesting areas, recreational zones), or background conditions. Consider modern approaches such as protecting ecosystem services, in addition to specific organism groups, as discussed by Apitz et al. (2012), Brown et al. (2017), and Landis et al. (2017).
 - Ensuring that the application of SedS-direct and SedS-food appropriately reflects the designated protection goals for a given site. For instance, in areas with significant human consumption of aquatic resources or critical habitat for piscivorous wildlife, the SedS-food may be the more pertinent driver for management decisions.

6. **Consideration of Natural Background Concentrations:** Formalized procedures will be developed for establishing and considering local natural background concentrations of contaminants, particularly for metals and naturally occurring organic compounds. Standards will not typically be set below established natural background ranges for a given region or sediment type.

C. How the Proposed Framework Addresses Identified Gaps

This modernized framework is designed to directly address the key deficiencies identified in the current sediment standards:

- **Protection of Non-Benthic Receptors and Indirect Exposure Pathways:** The introduction of the **SedS-food**, derived through TRGs, BSAFs, and FWMs, explicitly addresses the risks to wildlife and human consumers via food web transfer, a critical pathway not covered by the current benthic-focused standards (U.S. EPA, 2002; CSAP Society, 2015; BC ENV, 2024).
- **Inadequate Bioavailability Considerations:** Mandating OC normalization and AVS/SEM assessments at Tier 1, and allowing for advanced tools like PSDs in higher tiers, systematically integrates bioavailability into the assessment process, leading to more accurate risk predictions than bulk sediment comparisons alone (McGrath et al., 2019; Allen, 2011; Greenberg et al., 2014).
- **Outdated Toxicological Data and Approaches:** The framework mandates the use of the best available and current toxicological data and modern derivation methodologies (e.g., SSDs, mechanistic models) rather than relying on adjusted historical PELs (BC ENV, 2024; Warne et al., 2018; Greenfield et al., 2014).
- **Emerging Contaminants:** The framework includes a process for prioritizing and developing standards for emerging contaminants of concern (PFAS, microplastics, etc.), ensuring the standards remain relevant to contemporary environmental challenges (BC, 2024 (CSR) ; CCME, 1999a; SETAC, 2021).
- **Static Nature of Standards:** The guiding principle of adaptive management, with a commitment to a regular review and update cycle, ensures that the sediment standards will evolve with scientific advancements and changing environmental priorities (CSAP, 2017; U.S. EPA, 2005).
- **Weight-of-Evidence:** Formalizing a tiered approach that progresses towards WoE assessments for more complex sites moves beyond a simple numerical comparison, allowing for more holistic and scientifically robust decision-making (Chapman et al., 2002; Ontario MECP, 2008; Greenfield et al., 2014).

D. Implementation Considerations and Challenges

The successful implementation of this modernized framework will require careful planning and addressing several considerations and potential challenges:

- **Data Requirements and Availability:**

- Challenge: Deriving robust **SedS-direct** using SSDs and SedS-food using FWMs and TRGs requires substantial, high-quality toxicological and bioaccumulation data, which may be limited for some contaminants or BC-specific species.
- Consideration: Phased implementation, starting with contaminants with more robust datasets. Investment in targeted research to fill critical data gaps for BC-relevant species and ecosystems. Development of clear guidance on data quality requirements.
- **Technical Capacity and Expertise:**
 - Challenge: The application of advanced concepts like bioavailability modeling, FWMs, SSDs, passive sampling, eDNA, and probabilistic risk assessment methods requires specialized expertise that may need to be enhanced among regulators, consultants, and laboratories.
 - Consideration: Development of comprehensive technical guidance documents, training programs, and workshops. Fostering collaboration between government, academia, and consulting sectors.
- **Laboratory Capabilities and Analytical Methods:**
 - Challenge: Measurement of emerging contaminants (e.g., PFAS at very low ng/g levels), specialized bioavailability parameters (e.g., AVS/SEM, Cfree via PSDs), and conducting relevant chronic toxicity tests may require upgrades to laboratory analytical capabilities and standardization of methods across BC.
 - Consideration: Engage with analytical laboratories to understand current capabilities and future needs. Support method development and validation for new parameters. Establish clear analytical Quality Assurance/Quality Control (QA/QC) requirements.
- **Cost and Timelines for Site Assessments:**
 - Challenge: More comprehensive assessments, particularly at Tier 2/3 involving multiple lines of evidence, may increase the initial cost and time required for site investigations compared to the current simpler screening approach.
 - Consideration: The tiered approach is designed to focus intensive efforts on sites warranting them. Clear guidance on when and how to apply higher-tier assessments can optimize resource allocation. Long-term cost savings may be realized by avoiding unnecessary remediation or by more effective risk management.
- **Regulatory Integration and Clarity:**
 - Challenge: Clearly integrating the new dual-guideline system, tiered assessment framework, and AOP/BN/WoE principles into the existing CSR legal and procedural structure will be critical. Definitions (e.g., for site use categories if retained), compliance metrics, and roles/responsibilities (e.g., for Approved Professionals) will need to be clearly articulated.
 - Consideration: Iterative development of regulatory language with legal review.

Extensive stakeholder consultation during the drafting of new regulations and technical guidance.

- **Communication and Stakeholder Acceptance:**

- Challenge: Effectively communicating the scientific basis and practical implications of the new, more complex framework to a diverse range of stakeholders (industry, First Nations, public, environmental groups) will be essential for acceptance and successful implementation.
- Consideration: Develop a clear communication strategy. Provide accessible summaries and educational materials. Engage stakeholders throughout the development and rollout process to address concerns and build consensus.

Addressing these challenges proactively through strategic planning, investment in capacity building, phased implementation where appropriate, and ongoing stakeholder engagement will be key to the successful modernization of BC's sediment standards.

VI. Conclusions and Recommendations

This section will be completed once all preliminary scientific research, the jurisdictional scan, and all community and stakeholder engagement activities are concluded, and the proposed framework has been further refined. The final conclusions and recommendations will synthesize all findings to propose a comprehensive path forward for modernizing BC's sediment standards.

VII. References

(Note: Please apply hanging indents to each entry in the final document.)

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VIII. Appendices

Appendix A. Detailed methodology for scientific literature review:

The scientific literature review for this report involved systematic searches of peer-reviewed scientific journals (e.g., *Environmental Toxicology and Chemistry*, *Environmental Science & Technology*, *Integrated Environmental Assessment and Management*), government technical report databases (e.g., U.S. EPA, ECCC, provincial ministries), and publications from international organizations (e.g., Society of Environmental Toxicology and Chemistry (SETAC), Organisation for Economic Co-operation and Development (OECD)). Search terms included combinations of "sediment quality guidelines," "sediment criteria," "bioavailability," "bioaccumulation," "food web model," "risk assessment," specific contaminant names (e.g., "PFAS sediment"), and jurisdictional names. Priority was given to literature published within the last 10 to 15 years to capture the most current scientific understanding and regulatory practices. Reference lists of key review articles and reports were also scanned for additional relevant publications. The "P2 DRAFT Developing Modern SedQC" documents provided by the user, which themselves contain extensive literature reviews and jurisdictional scans, formed a core component of the reviewed materials.

Appendix B. List of jurisdictions included in the scan:

Canada:

- Federal:
 - CCME,
 - ECCC.
- Provinces:
 - British Columbia (current framework),
 - Ontario (MECP),
 - Quebec (MELCC) (Environment Canada & Ministère du Développement durable, Environnement et des Parcs du Québec, 2008),
 - Alberta (AEP), (AER, 2023)
 - Atlantic Provinces (via Atlantic RBCA). (Atlantic PIRI, 2023)

United States:

- Federal: U.S. EPA (EPA Headquarters, Office of Research and Development, Superfund Program, Great Lakes National Program Office).
- States:
 - Washington, (Washington State DoE, 2013a); Washington State DEP, 2013b; Washington State DoE, 2025)
 - California (REF),
 - Florida (Florida DEP, 2003)

Europe:

- European Union (general approach via Water Framework Directive) (EU, 2000),
- SedNet (European Sediment Network). (REF)
- Specific national approaches from countries like the Netherlands or Germany were considered as examples.

Australia/New Zealand:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018; Batley et al., 2014; Simpson et al., 2013).

Asia:

- China (Ministry of Ecology and Environment).
 - (REF)
- Japan (Ministry of the Environment).

- (U.S. Army Engineers, 1987; MOE Japan, 1997; Japan MOE, 2015)

Appendix C. Online survey questionnaire (Draft Example):

Modernizing BC's Sediment Quality Standards: Public & Stakeholder Survey (DRAFT)

Part 1: About You

1. Are you responding as an individual or on behalf of an organization?
2. If an organization, what sector do you represent (e.g., Industry, Consulting, ENGO, First Nation, Government, Academia, Other)?
3. Which region of BC are you most familiar with or concerned about regarding sediment quality?

- **Part 2: Importance and Concerns**

- 4. How important is the quality of sediment in BC's rivers, lakes, and marine environments to you? (Scale: Very Unimportant to Very Important)
- 5. What are your primary concerns regarding sediment contamination in BC? (Select all that apply: Impacts on fish/aquatic life, Impacts on wildlife, Human health risks from eating fish/shellfish, Human health risks from contact, Impacts on water quality, Economic impacts, Other)
- 6. Are there specific types of water bodies in BC (e.g., urban harbours, remote lakes, industrial foreshores) where you have particular concerns about sediment quality? Please specify.

- **Part 3: Protection Goals**

- 7. When modernizing sediment standards, which of the following protection goals do you consider most important? (Rank or select top 3): Protecting benthic organisms (life in the mud); Protecting fish populations; Protecting wildlife that eat aquatic organisms (e.g., birds, mammals); Protecting human health for those who eat fish or shellfish; Protecting human health for those who engage in water recreation; Ensuring standards are economically achievable.
- 8. Should sediment standards be stricter in areas considered ecologically sensitive or used for traditional food harvesting? (Yes/No/Unsure)

- **Part 4: Scientific Approaches**

- 9. Do you support incorporating the following scientific concepts more

- explicitly into BC's sediment standards? Bioavailability (how much contaminant is actually available to organisms): (Yes/No/Unsure); Bioaccumulation (contaminants building up in the food chain): (Yes/No/Unsure).
 -
- 10. Are there any specific contaminants you believe should be prioritized for new or updated sediment standards in BC (e.g., PFAS, microplastics, specific pesticides)?
- Part 5: General Feedback
 -
 - 11. Do you have any other comments or suggestions regarding the modernization of BC's sediment standards? (This is a simplified draft; the actual survey would be more detailed and undergo ethical review.)

Appendix D. Summarized, anonymized online survey results:

This appendix will contain summarized and anonymized results from the online public survey conducted from June 1 to July 31, 2025. Data collection is currently planned.

Appendix E. Detailed agenda and participant list (affiliations only, with consent) for the SSTAC/CEW session:

This appendix will contain the detailed agenda and a list of participant affiliations for the SSTAC session at the Canadian Ecotoxicity Workshop (October 7, 2025), to be populated after the event and with appropriate consents.

Planned Draft Agenda Outline:

- **Day 1:**
 - Introduction to BC's Sediment Standards Modernization Initiative.
 - Presentation: Current BC Standards & Identified Gaps.
 - Presentation: Overview of Jurisdictional Scan & International Best Practices.
 - Workshop 1: Methodologies for Deriving Benthic-Protective Guidelines (e.g., SSDs, EqP).
- **Day 2:**
 - Presentation: Proposed Approaches for Bioaccumulation & Food Web Protection.
 - Workshop 2: Integrating Bioavailability into Regulatory Frameworks.
 - Workshop 3: Addressing Emerging Contaminants (PFAS).
- **Day 3:**
 - Presentation: Interim Proposed Framework for BC.
 - Facilitated Discussion: Implementation Challenges & Opportunities.
 - Wrap-up & Next Steps.
- Poster Session: Ongoing throughout the workshop.

Appendix F. Summaries of presentations or abstracts from the SSTAC/CEW session (with consent):

This appendix will include summaries or abstracts of presentations delivered during the SSTAC session, to be compiled with presenter consent post-event.

Appendix G. Consolidated, non-attributed notes from SSTAC workshop discussions:

This appendix will provide consolidated, non-attributed notes capturing key themes and discussions from the SSTAC workshop sessions, to be compiled post-event.

Appendix H. Glossary of technical terms:

- **AEP:** Ministry of Environment and Protected Areas
- **ANZG:** Australian and New Zealand Guidelines for Fresh and Marine Water Quality
- **AOP:** Adverse Outcome Pathway
- **ATL:** Advisory Tissue Level
- **AVS:** Acid Volatile Sulfide (a measure of sulfide in sediment, influences metal bioavailability)
- **BAF:** Bioaccumulation Factor (ratio of contaminant in organism to contaminant in water)
- **BC:** British Columbia
- **BCC:** Bioaccumulative Chemical of Concern
- **BMD:** Benchmark Dose (a dose or concentration that produces a predetermined change in response rate of an adverse effect)
- **BN:** Bayesian Network
- **BSAF:** Biota-Sediment Accumulation Factor (ratio of contaminant in organism to contaminant in sediment, OC-normalized for organics)
- **CBR:** Critical Body Residue
- **CCME:** Canadian Council of Ministers of the Environment
- **CEW:** Canadian Ecotoxicity Workshop
- **C_{free}:** Freely dissolved concentration of a contaminant in porewater
- **COPC:** Contaminant of Potential Concern
- **CSAP:** Contaminated Sites Approved Professionals of BC
- **CSR:** Contaminated Sites Regulation
- **CSL:** Cleanup Screening Level (Washington State)
- **DEP:** Department of Environmental Protection
- **DGV:** Default Guideline Value (ANZG)
- **EC₂₀:** Effective Concentration causing a 20% effect in a tested population
- **EC₅₀:** Effective Concentration causing a 50% effect in a tested population
- **ECCC:** Environment and Climate Change Canada
- **eDNA:** Environmental Deoxyribonucleic Acid

- **EMA:** Environmental Management Act
- **EqP:** Equilibrium Partitioning
- **ERL/ERM:** Effects Range Low / Effects Range Median (NOAA empirical guidelines)
- **ESB:** Equilibrium Partitioning Sediment Benchmark (U.S. EPA)
- **ESL:** Ecological Screening Level
- **EU:** European Union
- **FEQG:** Federal Environmental Quality Guideline (Canada)
- **FEL:** Frequent Effect Level (Quebec)
-
- **FWM:** Food Web Model
- **GLWQI:** Great Lakes Water Quality Guidance
- **GV:** Guideline Value
- **HC₅:** Hazardous Concentration affecting 5% of species (derived from SSD)
- **HHRA:** Human Health Risk Assessment
- **HOC:** Hydrophobic Organic Contaminant
- **ISQG:** Interim Sediment Quality Guideline (CCME)
- **LEL:** Lowest Effect Level (Ontario)
- **LOE:** Line of Evidence
- **MECP:** Ministry of the Environment, Conservation and Parks
- **MEE:** Ministry of Ecology and Environment
- **MELCC:** Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parc
- **MOE:** Ministry of the Environment
- **NCP:** National Contingency Plan
- **NEL:** No Effect Level (Ontario)
- **NOAA:** National Oceanic and Atmospheric Association
- **OC:** Organic Carbon
- **OECD:** Organisation for Economic Co-operation and Development
- **OEHHA ATL:** Office of Environmental Health Hazard Assessment Advisory Tissue Level (California)
- **OEL:** Occasional Effect Level (Quebec)
- **PAH:** Polycyclic Aromatic Hydrocarbon
- **PBT:** Persistent, Bioaccumulative, and Toxic substance
- **PCB:** Polychlorinated Biphenyl
- **PE:** Polyethylene
- **PEL:** Probable Effect Level (CCME)
- **PEL-Q:** PEL-Quotient
- **PFAS:** Per- and Polyfluoroalkyl Substances
- **PHC:** Petroleum Hydrocarbon
- **PSD:** Passive Sampling Device
- **PSQS:** Provincial Sediment Quality Guideline (Ontario)

- **QA/QC:** Quality Assurance/Quality Control
- **REL:** Rare Effect Level (Quebec)
- **RBCA: Risk-Based Corrective Action**
- **RRM:** Relative Risk Model
- **SedQC:** Sediment Quality Criteria (BC, 2003 terminology)
- **SEL:** Severe Effect Level (Ontario)
- **SEM:** Simultaneously Extracted Metals (metals extracted with AVS, influences metal bioavailability)
- **SETAC:** Society of Environmental Toxicology and Chemistry
- **SMO:** Sediment Management Objective (BC, 2003 terminology)
- **SMS:** Sediment Management Standard
- **SPME:** Solid Phase Microextraction
- **SQAG:** Sediment Quality Assessment Guideline (Florida)
- **SQO:** Sediment Quality Objective (California)
- **SQS:** Sediment Quality Standard (general term; Washington State)
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- **SQT:** Sediment Quality Triad
- **SSD:** Species Sensitivity Distribution
- **SSTAC:** Science and Standards Technical Advisory Committee
- **SWRCB/OEHHA:** State Water Resources Control Board/Office of Environmental Health Hazard Assessment
- **TBT:** Tributyltin
- **TEL:** Threshold Effect Level (CCME-analogous)
- **TEQ:** Toxic Equivalents (for dioxins, furans, dioxin-like PCBs)
- **TRG:** Tissue Residue Guideline
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- **U.S. EPA:** United States Environmental Protection Agency
- **WFD:** Water Framework Directive (European Union)
- **WoE:** Weight-of-Evidence

Appendix I: Additional Relevant Sources and Links Considered During Framework Development

(This appendix includes references and links from the "White Paper v2 Master Bibliography" that were considered during the development of the source documents but are not directly cited in the main body of this report. APA 7th Edition style is used. Please apply hanging indents for each entry in the final document.)

Regulatory Documents & Guidelines (Not directly cited in main body)

- Many of the regulatory documents listed in the "White Paper v2 Master Bibliography" under "Regulatory Documents & Guidelines" may not all be directly cited in the main body of *this specific version* of the report but were part of the foundational knowledge.

Academic & Grey Literature (Not directly cited in main body)

- The "White Paper v2 Master Bibliography" contains an extensive list of "Academic & Grey Literature". Those not appearing in the main "References" section of this report are considered foundational and would be listed here. For example:
 - Adams, D. A., O'Connor, J. S., & Weisberg, S. B. (1998). *Sediment quality of the NY/NJ Harbor System: An investigation under the Regional Environmental Monitoring and Assessment Program (R-EMAP)* (EPA/902-R-98-001). United States Environmental Protection Agency Region II, Division of Environmental Sciences Assessment. (Considered in [develop_applicat_sqc_rep_nov19_wma.pdf](#))
 - Adams, W. J., Kimerle, R. A., & Barnett, Jr., J. W. (1992). Sediment quality and aquatic life assessment. *Environmental Science and Technology*, 26(10), 1864-1875. (Cited in MacDonald, Ingersoll, Smorong, & Lindscoog, 2003)
 - Anderson, B., Hunt, J., Tudor, S., Newman, J., Tjeerdema, R., Fairey, R., Oakden, J., Bretz, C., Wilson, C. J., LaCaro, F., Kapahi, G., Stephenson, M., Puckett, J., Anderson, J., Long, E. R., Flemming, T., & Summers, K. (1997). *Chemistry, toxicity and benthic community conditions in sediments of selected southern California bays and estuaries*. State Water Resources Control Board, State of California. (Considered in [develop_applicat_sqc_rep_nov19_wma.pdf](#))
 - BC Environment. (1988). *Waste Management Act: Special Waste Regulation*. B.C. Reg. 63/88. (Considered in [develop_applicat_sqc_rep_nov19_wma.pdf](#) and [sed_criteria_tech_app.pdf](#))
 - Field, L. J., MacDonald, D. D., Norton, S. B., Severn, C. G., & Ingersoll, C. G. (1999). Evaluating sediment chemistry and toxicity data using logistic regression modeling. *Environmental Toxicology and Chemistry*, 18(6), 1311–1322. (Considered in [develop_applicat_sqc_rep_nov19_wma.pdf](#) and [sed_criteria_tech_app.pdf](#))
 - Leppanen et al. (2024). Sediment Toxicity Tests: A Critical Review of Their Use in Environmental Regulations. *Environmental Toxicology & Chemistry*. (Note: Specific volume/page needed for full citation). (Considered in [P2 DRAFT Developing Modern SedQC \(ChatGPT o3 w DR\).docx](#))
 - Long, E. R., & Morgan, L. G. (1991). *The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program* (NOAA Technical Memorandum NOS OMA 52). National Oceanic and

Atmospheric Administration. (Cited in MWLAP, 2003; MacDonald, Ingersoll, Smorong, & Lindscoog, 2003)

- MacDonald, D. D. (1998). *Applications of sediment quality guidelines in the remediation of sediment contaminated sites in British Columbia*. Prepared for Ministry of Environment, Lands and Parks. (Considered in develop_applicat_sqc_rep_nov19_wma.pdf)
- Persaud, D., Jaagumagi, R., & Hayton, A. (1993). *Guidelines for the protection and management of aquatic sediment quality in Ontario*. Standards Development Branch, Ontario Ministry of Environment and Energy. (Cited in MacDonald, Ingersoll, Smorong, & Lindscoog, 2003)
- Swartz, R. C. (1999). Consensus sediment quality guidelines for PAH mixtures. *Environmental Toxicology and Chemistry*, 18(4), 780–787. (Cited in MacDonald, Ingersoll, Smorong, & Lindscoog, 2003)
- U.S. Environmental Protection Agency. (1997). *The incidence and severity of sediment contamination in surface waters of the United States: Volume 1: National Sediment Quality Survey* (EPA/823/R-97/006). (Cited in MacDonald, Ingersoll, Smorong, & Lindscoog, 2003)
- U.S. Environmental Protection Agency (U.S. EPA). (2000). *Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines* (EPA 905/R-00/007). Great Lakes National Program Office. (Considered in develop_applicat_sqc_rep_nov19_wma.pdf and sed_criteria_tech_app.pdf)
- Washington State Department of Ecology. (1991). *Sediment management standards. Washington Administrative Code. Chapter 173-204 WAC*. (Cited in MWLAP, 2003)

Web-Based Resources & Databases (Not directly cited in main body)

(The following are derived from the "White Paper v2 Master Bibliography" Appendix I and other web links mentioned in the source documents. Access dates are as provided in the source, e.g., April 18, 2025, or May 10, 2025, or as generally noted "during 2023-2024 research phase" or similar if specified in the "Prompt" example.)

- Alberta Energy Regulator. 2025. *Contamination Management Policy And Guidelines*. Retrieved April 18, 2025, from <https://www.aer.ca/regulations-and-compliance-enforcement/site-closure-requirements/remediation/contamination-management-policy-and-guidelines>
 - Brief description: Provides AER's policy and guidelines for managing contamination.
- Alberta Energy Regulator. 2025. *Manual 021: Contamination Management*. Retrieved April 18, 2025, from <https://www.aer.ca/documents/manuals/Manual021.pdf>

- Brief description: Detailed manual on contamination management from AER.
- Atlanticrbca.com. 2022. *ATLANTIC RBCA ENVIRONMENTAL QUALITY STANDARDS RATIONALE AND GUIDANCE DOCUMENT*. Retrieved April 18, 2025, from https://atlanticrbca.com/wp-content/files_mf/1658170677Atlantic_RBCA_EQS_Rationale_and_Guidance_Document_July_2021_Updated_July_13_2022_FINAL.pdf
 - Brief description: Provides guidance on the Atlantic Risk-Based Corrective Action framework including sediment standards.
- BC Laws. 2025. *Table of Contents - Contaminated Sites Regulation*. Retrieved April 18, 2025, from https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/375_96_00
 - Brief description: Access to BC's Contaminated Sites Regulation.
- Canada.ca. 2025. *Federal Environmental Quality Guidelines (FEQGs)*. Retrieved April 18, 2025, from <https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/federal-environmental-quality-guidelines.html>
 - Brief description: Information on Canada's FEQGs.
- Canadian Council of Ministers of the Environment (CCME). 2025. *Canadian Environmental Quality Guidelines (CEQGs)*. Retrieved April 18, 2025, from <https://ccme.ca/en/current-activities/canadian-environmental-quality-guidelines>
 - Brief description: Website for the Canadian Council of Ministers of the Environment, providing access to national environmental guidelines.
- CLU-IN (Contaminated Land-In Information Network - EPA). 2025. *[Resources on sediment remediation, e.g., Japanese standards or U.S. EPA ESB procedures]*. (Example: Specific link for U.S. Environmental Protection Agency. (2003). *Procedures for the derivation of equilibrium partitioning sediment benchmarks (ESBs) for the protection of benthic organisms: PAH mixtures* (EPA-600-R-02-013). Retrieved from <https://clu-in.org/conf/tio/porewater1/resources/EPA-ESB-Procedures-PAH-mixtures.pdf>)
 - Brief description: EPA's hazardous waste clean-up information website.
- Health Canada. 2025. *Guidance on Human Health Risk Assessment*. Retrieved May 10, 2025, from <https://www.canada.ca/en/health-canada.html> (Search for risk assessment guidance)
 - Brief description: Provides methodologies and toxicity reference values for conducting human health risk assessments, relevant for the seafood consumption pathway.
- ITRC (Interstate Technology & Regulatory Council). 2025. *Contaminated Sediments Guidance*. Retrieved May 10, 2025, from <https://itrcweb.org/> (Search for sediment guidance, e.g., "Contaminated Sediments – Bioavailability")
 - Brief description: ITRC provides guidance documents on environmental

remediation technologies and approaches, including for contaminated sediments.

- National Oceanic and Atmospheric Administration (NOAA). 2025. *Sediment Quality Guidelines*. (<https://www.noaa.gov/>). Example: Long, E. R., & Morgan, L. G. (1991). *The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program* (NOAA Technical Memorandum NOS OMA 52).
 - Brief description: NOAA has historically developed widely used empirical sediment quality guidelines like ERLs and ERM.
- Ontario Ministry of the Environment, Conservation and Parks. 2025. *Provincial Sediment Quality Guidelines*. Retrieved May 10, 2025, from <https://www.ontario.ca/page/provincial-sediment-quality-guidelines>
 - Brief description: Provides access to Ontario's PSQs, which include NEL, LEL, and SEL values, forming a key Canadian provincial framework.
- SedNet. 2025. *[Various Documents]*. Retrieved May 10, 2025, from <https://sednet.org/>
 - Brief description: European Sediment Network, providing resources and guidance on sediment management in the context of EU directives.
- SETAC (Society of Environmental Toxicology and Chemistry). 2025. *Sediment Advisory Group Resources*. Retrieved May 10, 2025, from <https://www.setac.org/> (Search for sediment relevant publications/groups)
 - Brief description: SETAC is a professional organization that publishes extensive research and guidance on sediment quality assessment and ecotoxicology.
- U.S. Army Corps of Engineers Northwestern Division (NWS). 2025. *[Puget Sound Dredged Disposal Analysis]*. (<https://www.nws.usace.army.mil/Missions/Civil-Works/Dredging/>)
 - Brief description: Information related to dredging and sediment management in Puget Sound, relevant to Washington State standards.
- U.S. Environmental Protection Agency (EPA). 2025. *Sediment Management Standards (Washington State)*. (<https://www.epa.gov/wa/washington-state-sediment-management-standards>)
 - Brief description: EPA resources related to Washington State's Sediment Management Standards.
- Water Quality Australia. 2025. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality - Toxicant default guideline values for sediment quality*. Retrieved May 10, 2025, from <https://www.waterquality.gov.au/guidelines/anz-fresh-marine/toxicant-default-guideline-values/sediment>
 - Brief description: Provides detailed sediment quality guideline values from the ANZG 2019 framework. The website also includes guidelines for deriving site specific values.

- Waterboards.ca.gov (California State Water Resources Control Board). 2025. (Various dates). *Sediment Quality Objectives*. (https://www.waterboards.ca.gov/water_issues/programs/tmdl/docs/303d_policydocs/240.pdf)
 - Brief description: Information regarding California's framework for sediment quality objectives, including human health and aquatic life protection.

(Note: This Appendix I is populated based on the instructions to include non-directly cited but considered foundational references and links from the source documents and the "White Paper v2 Master Bibliography". Full population would involve systematically going through all source document bibliographies and the Master Bibliography's Appendix I section and listing all items not found in the main "References" section above, ensuring APA 7th formatting with descriptions and access dates for links as per the prompt.)

Please remember that hanging indents need to be applied to Section VII (References) and Appendix I in the final formatted document (e.g., DOCX, PDF).