Health Canada | Santé Canada

Your health and safety… our priority. | *Votre santé et votre sécurité… notre priorité.*

Supplemental Guidance on Human Health Risk Assessment of Contaminated Sediments: Direct Contact Pathway

Federal Contaminated Site Risk Assessment in Canada

Canada

Health Canada is the federal department responsible for helping the people of Canada maintain and improve their health. We assess the safety of drugs and many consumer products, help improve the safety of food, and provide information to Canadians to help them make healthy decisions. We provide health services to First Nations people and to Inuit communities. We work with the provinces to ensure our health care system serves the needs of Canadians.

Également disponible en français sous le titre :
L'évaluation des risques pour les sites contaminés fédéraux au Canada : Guide supplémentaire sur l'évaluation des risques pour la santé humaine liés aux sédiments contaminés : Voie du contact direct

To obtain additional information, please contact:

Health Canada
Address Locator 0900C2
Ottawa, ON K1A 0K9
Tel.: 613-957-2991
Toll free: 1-866-225-0709
Fax: 613-941-5366
TTY: 1-800-465-7735
Email: publications@hc-sc.gc.ca

This publication can be made available in alternative formats upon request.

Publication date: March 2017

Cat.: H144-41/2017E-PDF
ISBN: 978-0-660-07989-9
Pub.: 160382

FEDERAL CONTAMINATED SITE RISK ASSESSMENT IN CANADA

SUPPLEMENTAL GUIDANCE ON HUMAN HEALTH RISK ASSESSMENT OF CONTAMINATED SEDIMENTS: DIRECT CONTACT PATHWAY

March 2017

Prepared by:
Contaminated Sites Division
Safe Environments Directorate

TABLE OF CONTENTS

LIST OF FIGURES AND EXHIBIT

LIST OF TABLES

PREFACE

The Federal Contaminated Sites Action Plan (FCSAP) is a program of the Government of Canada designed to achieve improved and continuing federal environmental stewardship as it relates to contaminated sites located on federally owned or operated properties or non-federal lands for which the federal government has accepted full responsibility. Guidance documents on human health risk assessment (HHRA) prepared by the Contaminated Sites Division of Health Canada, in support of the FCSAP, may be obtained by contacting the Contaminated Sites Division at cs-sc@hc-sc.gc.ca.

This guidance document, *Federal Contaminated Site Risk Assessment in Canada: Supplemental Guidance on Human Health Risk Assessment of Contaminated Sediments: Direct Contact Pathway*, was prepared for the benefit of custodial departments. As is common with any national guidance, this document will not satisfy all of the requirements presented by contaminated sites, custodial departments or risk assessors in every case. As the practice of HHRA advances and as the FCSAP proceeds, new and updated information on various aspects of HHRA will be published. Therefore, revisions to this document will likely be necessary from time to time to reflect new information. Health Canada should be consulted at the address below to confirm that the version of the document in your possession is the most recent edition and that the most recent assumptions, parameters, and so on, are being used.

In addition, Health Canada requests that feedback on this document be directed to: Contaminated Sites Division, Safe Environments Directorate, Healthy Environments and Consumer Product Safety, Health Canada, email: cs-sc@hc-sc.gc.ca.

See also: www.hc-sc.gc.ca/ewh-semt/contamsite/index-eng.php

This guidance document was written by the Contaminated Sites Division of Health Canada based on earlier reports written by Intrinsik Environmental Sciences Inc., Golder Associates, Environ International Corp., Wilson Scientific Consulting Ltd. and Meridian Environmental Inc. under contract to Health Canada. Health Canada acknowledges the feedback and review comments received from a variety of government sources, academia and consultants during the preparation of this guidance document, particularly the input received by participants of the June 2010 Health Canada workshop, "Approaches for Human Health-Based Sediment Quality Guidelines and Sediment Risk Assessment" held in Vancouver, BC.

Comments and feedback were sought in an attempt to make the document as complete and defensible as possible within the limitations presented by the FCSAP and Health Canada commitments, policies and obligations with respect to health risk assessment and protection.

ABBREVIATIONS AND ACRONYMS

CCME	Canadian Council of Ministers of the Environment
CEM	Conceptual Exposure Model
COPC	Contaminant of Potential Concern
CSD	Contaminated Sites Division
CSM	Conceptual Site Model
DQRA	Detailed Quantitative Risk Assessment
FCSAP	Federal Contaminated Sites Action Plan
HC	Health Canada
HHRA	Human Health Risk Assessment
NR	Not Reported
OC	Organic Carbon, total content
PQRA	Preliminary Quantitative Risk Assessment
RBA	Relative Bioavailability Adjustment
$SedIR_{HM}$	Sediment Ingestion Rate, hand-to-mouth
$SedIR_{SS}$	Sediment Ingestion Rate, suspended sediment
SQG	Soil Quality Guideline
TRVs	Toxicological Reference Values
US EPA	United States Environmental Protection Agency

GLOSSARY

Authigenic sediments: Pertaining to sediments formed in place on the floor of the water body. The formation of this sediment depends on local geochemical conditions, elemental abundances, water characteristics, proximity of hydrothermal sources, and rate of sediment accumulation.

Bedded sediments: Unconsolidated (i.e. loose) matter that accumulates in the bottom of natural water bodies, including sediments submerged under water and sediments that may become periodically exposed (e.g. intertidal sediments and wetlands).

Bioaccumulation: The net accumulation of a chemical in an organism, resulting from exposure of the organism to a chemical in environmental media (e.g. water, sediment or food items) by any or all possible exposure routes.

Bioavailability: In mammalian toxicology, and human health risk assessment, this refers to the fraction of the administered dose of a chemical that is absorbed and is available for systemic circulation in the body.

Biogenic sediments: Pertaining to sediments produced by living organisms or biological processes; that is, either constituents of the organism or secretions of the organism.

Biomagnification: Term used to describe the observed increase in the chemical tissue concentration in organisms with increasing trophic level in the food chain. Biomagnification results primarily through dietary accumulation (i.e. accumulation of a chemical from consumption of lower trophic level prey items by higher trophic level organisms).

Conceptual exposure model (CEM): A “snapshot” that illustrates (e.g. in tabular, pictorial or schematic form) exposure pathways by which people may come into contact with contaminated media at a site. It is used as a tool to help conceptualize the site on paper, to ensure that all the appropriate media, exposure pathways, and receptor information are considered.

Conceptual site model (CSM): A visual representation that includes the same information as a CEM, but also considers how the media at the site became contaminated, as well as specific contaminant fate and transport pathways. It is used as a tool to help prioritize the investigation as it advances, helping to target media or specific pathways that appear to drive risk or hazard. The CSM should be iterative and revised from time to time, to ensure it is still relevant, as the risk assessment is refined.

Contaminant of potential concern (COPC): A contaminant that has the potential to cause risk or adverse effects to humans at a site. When assessing COPCs in sediment, considerations include whether the contaminant is naturally occurring in the region and the specific exposure scenarios associated with this matrix.

Dermal loading (or dermal adherence): Relating to the concentration of a chemical in a substance that is in contact with a given area of skin; also referred to as skin adherence. This is directly correlated to exposure.

Deterministic assessment: Assessments based on the use of single “point estimates” to represent the input parameters in the exposure and risk calculations to produce a single estimate of risk or hazard. It does not take into account the variability of the parameters. The uncertainty and variability are discussed qualitatively in a deterministic risk assessment.

Elimination half-life: The time it takes for half of the initial amount of a chemical in the body to be eliminated from the body through metabolism and excretion functions (i.e. the body’s cleansing function that involves conversion of the chemical to become more water-soluble and subsequent elimination from the body).

Exposed sediments: Sediments not submerged under water; they are given special consideration since the dermal adherence may be expected to be higher than for other sediment types.

Mode of action: The key steps in a toxic response following exposure to a chemical that result in an effect in an organism.

Non-threshold chemical: A chemical that is considered to have some potential to cause adverse health effects at any dose. Non-threshold chemicals are assumed to have a dose-response curve that do not exhibit a clear threshold dose. This classification is normally applied to genotoxic carcinogens and teratogens.

Probabilistic assessment: An assessment based on probability distribution functions, instead of point estimates to describe input and output parameters, thereby addressing variability and uncertainty in key assumptions and parameters used in the assessment.

Relative bioavailability: A term that is used to describe the difference in bioavailability between different chemical forms, or between different environmental media (e.g. drinking water vs. food) or exposure routes (e.g. oral vs. dermal). In risk assessment, it is most commonly used to compare the bioavailability of a chemical in the environmental matrix of interest relative to the dosing medium used in the toxicity study from which the toxicity reference value (TRV) is derived.

Seafood: All freshwater and marine aquatic biota (including, but not limited to, macroalgae, roots and other plant parts from marshes, fish or shellfish roe, fish, shellfish, seabirds, seabird eggs and marine mammals) that may be consumed by humans.

Sediments: Bottom deposits in aquatic environments that are composed of particulate material (of various sizes, shapes, mineralogy) from various sources (e.g. terrigenous, biogenic, authigenic).

Suspended sediments: Fine particles that remain in suspension in water and are moved by water.

Terrigenous sediments: Pertaining to marine sediments that are derived from the erosion of terrestrial material (e.g. rocks and soil).

Threshold chemical: A chemical that is considered to show adverse health effects only once a certain dose (the threshold) is reached or exceeded. Threshold chemicals exhibit a non-linear dose-response curve with a clear threshold dose below which no toxic effects are observed.

Tolerable daily intake (TDI): Estimate of the amount of a threshold chemical to which people can be exposed to over a lifetime, without an appreciable risk of adverse health effects.

Toxicological reference value (TRV): Reference values that are established in order to qualify or quantify the potential risk of toxic effects that could result from exposure to chemicals. For the purpose of toxicity assessment, TRVs are classified based on whether the chemical is considered to be a threshold (e.g. non-carcinogenic), or non-threshold (e.g. carcinogenic) chemical.

1.0 INTRODUCTION

This document was developed in support of the Government of Canada's Federal Contaminated Sites Action Plan (FCSAP). The program is designed to ensure improved and continuing federal environmental stewardship as it relates to contaminated sites located on federally owned or operated properties or non-federal lands for which the federal government has accepted full responsibility. This document addresses the evaluation of human exposure to chemicals in sediments via direct contact with sediments. Other guidance documents on human health risk assessment (HHRA), prepared by the Contaminated Sites Division (CSD) of Health Canada (HC) in support of the FCSAP, are listed on the HC website (www.hc-sc.gc.ca/ewh-semt/contamsite/docs/index-eng.php), and may be obtained by contacting the Contaminated Sites Division at cs-sc@hc-sc.gc.ca.

Ecological health risks are evaluated separately from human health risks. Please refer to the FCSAP Ecological Risk Assessment Guidance (FCSAP 2010a, b; 2012a, b; 2013; in preparation) and consult Environment and Climate Change Canada and Fisheries and Oceans Canada for further guidance.

1.1 Purpose

Health Canada's (2012; 2010) Preliminary Quantitative Risk Assessment (PQRA) and Detailed Quantitative Risk Assessment (DQRA) guidance are applicable to federal contaminated sites; however, there are unique considerations relevant to aquatic sites that are not covered in these general guidance documents. The purpose of this supplemental guidance document is to provide information related to evaluating human exposure to chemicals in sediments via direct contact (i.e. incidental ingestion, dermal contact and inhalation of particulates), especially where receptor characteristics and exposure scenarios for aquatic sediment sites may differ from terrestrial (soil) sites.

In establishing sediment guidelines for the protection of aquatic life, the Canadian Council of Ministers of the Environment (CCME 1995) defines sediments as *"bottom deposits in aquatic environments that are composed of particulate material (of various sizes, shapes, mineralogy) from various sources (e.g. terrigenous, biogenic, authigenic)."* Two criteria are used to distinguish between human exposure to sediment and human exposure to soil. The first criterion is that sediment is, at least periodically or seasonally, underwater or saturated with water and/or may be routinely suspended in water, while soil remains consistently drier. The second criterion is that human activity and/or exposure that occurs at an aquatic environment is expected to differ substantially from that in a terrestrial environment. The guidance presented in the document is intended to be used when human exposure occurs at sediment sites.

The following types of sediments are addressed in this document:

- Bedded sediments, which include sediments submerged under water and sediments that may become periodically exposed (e.g. intertidal sediments and wetlands); and
- Sediments suspended in the water column.

People may also be exposed indirectly to chemicals in sediment when the chemicals are transported to other media (e.g. surface water) or when chemicals are incorporated into the food chain through bioaccumulation or biomagnification. Please consult HC for guidance on evaluating health risks associated with the consumption of seafood (fish, shellfish, plants and algae, etc.) or exposure to chemicals in surface water at aquatic sites.

The guidance provided in this document applies to both marine and freshwater environments on federal contaminated sites being managed under FCSAP. It is not applicable to constructed wetlands and lagoons that are used to treat storm water run-off or industrial and/or municipal effluents as part of a wastewater treatment system.

1.2 Background

Sediment is a major residency and exposure medium for most chemicals of concern in aquatic systems. Aquatic sites with contaminated sediment are often a greater challenge to characterize, assess and manage than terrestrial sites for various reasons including the following:

- Aquatic sites may be large, diverse and/or complex (i.e. have mixed use, mixed ownership and overlapping legal jurisdictions).
- There may be many point and non-point sources of chemicals, some of which can be active, and difficult to control (e.g. stormwater discharges).
- The aquatic environment is typically more dynamic, and sediments may be highly mobile and migrate to other areas. Consequently, sediment contamination may be diffuse and more easily dispersed or displaced.
- Understanding sediment dynamics and chemical fate and transport can be difficult and may require complex environmental modelling, depending on the characteristics of the water body.
- Characterizing the magnitude and extent of contamination in sediments can be more challenging and may require different sediment management approaches.
- Available HHRA guidance tends to be focused on terrestrial sites (i.e. soils) more than aquatic sites (i.e. sediments).
- Remedial work in an aquatic environment may be difficult from an engineering perspective and may be more costly and technically challenging than in a terrestrial environment.

Human activities and exposure characteristics at aquatic sites may differ from those associated with terrestrial sites. For example, dermal loading (or adherence) factors, incidental ingestion rates and exposed skin surface area for sediment exposure scenarios may be greater than those for terrestrial activities associated with soil. Exposure frequency and duration may also differ between aquatic and terrestrial sites.

2.0 PROBLEM FORMULATION

2.1 Generic Sediment Exposure Scenarios

This section presents three generic exposure scenarios for aquatic sites that may be considered analogous to the land use scenarios typically considered for terrestrial sites (residential/parkland, commercial, etc.). These exposure scenarios (Recreational High-Contact, Recreational Low-Contact, and Commercial/Industrial) are intended to be representative of typical human activities that may occur at sediment sites. For sites that may be subject to higher frequency or intensity of use, or that are used in a manner that differs from these generic scenarios, receptors and exposure parameters should be adjusted accordingly within the risk assessment. This guidance does not replace the use of professional judgment or the requirement for scientific rationale in a risk assessment. Details of each of these scenarios, including representative activities and exposure frequency and duration, are provided in Table 1.

The three generic sediment exposure scenarios are highlighted to illustrate how different aquatic use scenarios may result in substantially different exposure patterns for people who access the site. As a result, some of the key receptor characteristics and exposure parameters may vary between these three exposure scenarios. For example, sediment ingestion rates selected for a high-contact exposure scenario may be greater than those that would be appropriate for some recreational low-contact exposure scenarios and some commercial/industrial exposure scenarios. Also, the exposure frequency and duration may be substantially different for each of these generic exposure scenarios. However, the overall approach for evaluating each of the generic exposure scenarios outlined in Table 1 (and other site-specific exposure) would generally be the same. The guidance in this document generally applies to each of the three exposure scenarios, and where possible, differences in how each of the three generic exposure scenarios would be evaluated are highlighted.

The physical setting of the site, location of impacted sediments and access to the site are also important to consider. At some sites, sediments may be periodically exposed, while at others, sediments may be continuously under water. These conditions may affect how people come in contact with, and are exposed to the sediments. Similarly, the depth of impacted sediments below the water surface, type of sediment or substrate type, sediment particle size and the proximity of impacted sediments to the shoreline may also affect how people are exposed to contaminants in sediments. There may also be situations where the material is more representative of sediment at some times of the year and more representative of soil at other times (e.g. wetlands that dry out periodically). In this case, it may be necessary to evaluate both exposure scenarios if human exposure is assessed.

Table 1. Description of Generic Sediment Exposure Scenarios

Generic Sediment Exposure Scenario	Recreational Low-Contact	Recreational High-Contact	Commercial/Industrial
Receptors	General Public – All Ages	General Public – All Ages	Adult Workers
Examples of Representative Activities[1]	• Boating/kayaking/etc. • Deep water swimming • Recreational fishing • Waterskiing/wind surfing • Walking/beachcombing	• Shoreline play • Recreational and subsistence shellfish/bait/vegetation harvesting and fishing • Picnicking • Wading and swimming (in shallow waters) • Body surfing	• Commercial fishing for fish or shellfish • Mariculture/aquaculture • Boat maintenance • Dock/infrastructure maintenance • Miscellaneous shoreline work
Exposure Frequency and Duration	• Year-round or seasonal • Brief incidental contact with shoreline and suspended sediment	• Seasonal • Prolonged incidental contact with shoreline and suspended sediment	• Year-round or seasonal following a typical work schedule • Prolonged incidental contact with shoreline and suspended sediment

[1] These are examples only, and this is a non-exhaustive list.

2.2 Screening and Identification of Contaminants of Potential Concern (COPC)

The purpose of chemical screening at the problem formulation stage of a human health risk assessment is to identify chemicals that currently pose, or have the potential to pose, risks to human health. These chemicals are carried forward to the subsequent stages of a risk assessment and are referred to as contaminants of potential concern (COPC). Chemical screening involves identifying appropriate sediment screening criteria and comparing measured concentrations against the screening criteria, comparing measured concentrations against background conditions, and selecting COPCs.

2.2.1 Sediment Screening Criteria

Currently, there are no human health-based sediment criteria or guidelines established by a Canadian jurisdiction. The few human health-based sediment criteria currently available from other jurisdictions would not be directly applicable to most Canadian federal contaminated sites, as they generally do not consider all potentially relevant exposure pathways, or they rely on regional data to assist with the development of site-specific screening criteria. For example, the New York Department of Environmental Conservation guidelines are based only on seafood consumption (NY DEC 1999) while Washington State Department of Ecology (2013; 2015) has published narrative human health sediment standards and an approach for developing site-specific standards for sediments.

In the absence of applicable human health-based sediment guidelines, sediment concentrations may be screened against available human health-based residential/parkland soil quality guidelines (or criteria) for scenarios where only direct contact of contaminants from sediment is expected. Soil quality guidelines were developed based on exposure factors specific to human interactions with soil. Given that human exposure to sediments is typically different from human exposure to soil (e.g. potentially greater dermal adherence and ingestion rates for sediments), soil quality guidelines may not be sufficiently protective of human health for some sediment exposure scenarios, particularly when people are expected to visit a site regularly to participate in high-contact activities (such as those identified in Table 1). In this case, site-specific sediment screening values may be derived. Alternatively, COPCs may be identified by comparing site data with regional background data, as described in section 2.2.2.

In situations where soil quality guidelines are considered relevant and appropriate for screening, only the human health-based guidelines for the relevant corresponding sediment exposure pathways should be considered. In particular, at many sites, incidental ingestion of and dermal contact with sediments may be the only operable pathways. In this case, only the human health-based soil quality guidelines for dermal contact and incidental ingestion would be considered relevant sediment screening values. In cases where a soil quality guideline is based on the inhalation exposure pathway, this guideline may be relevant for the site only if sediments dry out periodically.

For the purpose of screening COPCs at federal sites, the relevant CCME Canadian Soil Quality Guidelines (SQGs) for human health would generally be considered the most appropriate screening values. Where human health-based CCME SQGs are unavailable, human health-based soil criteria or guidelines from another jurisdiction may be selected, provided they offer the same level of protection inherent in the CCME SQGs. In some cases, criteria from another jurisdiction may need to be adjusted to be consistent with the health protection endpoints prescribed by Health Canada and CCME (refer to HC 2010, Section 3.4.2.1 for further guidance). Appropriate rationale for the criteria that are used to screen sediments should be provided, and the uncertainties associated with the selected criteria should be noted.

Soil criteria do not account for bioaccumulative or biomagnifying chemicals in aquatic foods. Soil criteria are therefore not suitable for identifying bioaccumulative or biomagnifying chemicals that should be considered in evaluating risks associated with the consumption of seafood (i.e. fish, shellfish, aquatic vegetation or aquatic birds) from the site. Please contact Health Canada for further guidance on screening COPCs and evaluating potential health risks at sites where people may consume seafood.

2.2.2 Background/Reference Levels

Sediment COPCs at an impacted site should be compared with sediment concentrations from reference or background sites to allow for identification of chemicals that may be elevated on a regional basis due to a natural or anthropogenic non-point source unrelated to the site. Two approaches are commonly used for sampling reference sediment sites:

- the independent reference sites sampling approach, and
- the gradient-based sampling approach.

The objective of either approach is to identify sampling locations that are outside of the contaminated areas and/or the mixing zone.

Independent reference sites that have physical, chemical, and geological characteristics that are as similar as possible to the contaminated site but that are unrelated to the contaminant source should be used. They should be located close to the contaminated site without being impacted by the activities and chemicals from the site or other localized contaminant sources such as point sources. Reference sites should be representative of regional chemical concentrations, attributed to regional background sources. More than one reference site may be needed if the site exhibits a range of physical, chemical or geological characteristics. The following are important characteristics that should be considered, where possible, when identifying reference sites:

- Type of water body (marine, estuarine, freshwater, lake, river, etc.)
- Sediment or substrate type
- Sediment characteristics (grain size, total organic carbon content, oxidation-reduction (redox) potential, etc.)
- Distance from known point sources of contamination
- Natural geological conditions (i.e. geological history, sedimentation rates)
- Bathymetry (i.e. bottom topography, water depth, variation in depth, sediment transport patterns, including erosional and depositional zones)
- Hydrographic considerations (such as velocity, direction of currents, tidal zone and tidal conditions)

It may not be feasible to consider all of the characteristics listed above, and in some cases the effort required may not be warranted. At a minimum, the type of water body, sediment type and sediment characteristics should be as closely matched as possible.

In some cases, it may not be possible to locate a suitable reference site(s), and the site data may instead be compared to regional data (i.e. from a database compiled by another party) or historical data collected prior to the human activities that resulted in impacts to the site, or the surficial sediments may be compared to deeper uncontaminated sediments.

A gradient-based sampling approach may be considered if no suitable reference sites or regional data are available. For example, if no suitable upstream reference locations can be identified in a river, a simple gradient design, where sampling locations at varying distances downstream from the source, may be appropriate. Similarly, a radial gradient design may be appropriate in a marine water body or lake where tides and currents may result in the deposition of contaminants in multiple directions and at various distances from the source. In a gradient approach, a number of samples would be taken at increasing distance from the source. When using a gradient approach, the reference area(s) would be considered the location(s) where the site-related impacts are no longer discernible. There may be a need to establish more than one reference area or condition depending on the geophysical characteristics and/or complexity of the water body. Chemical concentration gradients in sediments should ideally be independent of environmental gradients (e.g. water depth, salinity); however, this is not always possible. When independence from environmental conditions cannot be established, multivariate analyses can be used to minimize confounding factors, or a different sampling approach may be necessary. Further information on various gradient approaches can be found in EC (2010), FCSAP (in preparation) and CCME (2016).

In all cases, it is necessary to provide a thorough justification of the choice of reference sites. When screening against reference samples, those chemicals that are site-related and that are significantly greater in site-impacted sediments than in reference samples should be carried forward as COPCs. If chemical concentrations are considered elevated but not specifically related to the site in question, the risk assessor may still consider retaining the substance as a COPC in the HHRA to provide a thorough evaluation of health risks associated with the site. In some cases, a chemical suspected of being regionally elevated may be excluded from further consideration, provided that adequate rationale for its exclusion is given in the HHRA. If a chemical that is suspected to be regionally elevated is not retained for further evaluation, the risk assessment should clearly indicate that health risks associated with the chemical have not been evaluated.

Guidance on statistical methods that can be used to compare test sites to reference sites can be found in US EPA (2015) and CCME (2016). Sufficient rationale should be provided for excluding a chemical based on a comparison with data from a reference site.

2.3 Receptor Identification

Humans at aquatic sites may include workers, sport and subsistence fishers, and people of all ages from the general public and aboriginal communities. The activity patterns and receptor characteristics of people at sediment sites may be quite different compared to those at terrestrial sites (refer to Table 1 and Section 3.3), but the age classes of the receptors used (i.e. infant, toddler, child, teen, adult) remain the same.

2.4 Exposure Pathways Identification

The exposure pathways for direct human contact with chemicals in sediment may include

- incidental ingestion of bedded sediment,
- dermal absorption from sediments adhering to skin,
- incidental ingestion of suspended sediment in surface water, and
- inhalation of airborne particles (for sediments that dry out periodically).

Dermal adherence of underwater bedded sediments and suspended sediments is expected to be substantially lower than dermal adherence of exposed sediments (i.e. sediment not under water). Therefore, for sites where people are expected to be in contact with chemicals in both exposed sediment and underwater bedded sediments or suspended sediments in water, it may be reasonable (and conservative) to assume that people are in contact with exposed sediment for the entire exposure duration. In cases where chemicals are found only in sediments permanently submerged and human contact with the sediments is expected, dermal exposure to both bedded and suspended sediments in water may need to be considered.

The inhalation of airborne particles would typically only be a concern at sites where sediments dry out periodically. Under some circumstances, people may be exposed to volatile substances via the inhalation of vapours migrating from contaminated sediment where sediments dry out periodically.

People may also be exposed to chemicals in surface water at aquatic sites or to chemicals that have been incorporated into the food chain through bioaccumulation. Exposure to chemicals via these pathways should be evaluated separately and is beyond the scope of this document. Professional judgment should be used, and rationale should always be provided when identifying operable exposure pathways on a site-specific basis.

2.5 Conceptual Exposure and Conceptual Site Models

A conceptual exposure model (CEM) illustrates the exposure pathways by which people may come into contact with contaminated media at a site. A conceptual site model (CSM) includes the same information as a CEM but also includes information on how the media at the site became contaminated. In particular, the CSM summarizes information about the chemical source(s), release mechanisms, potential transport pathways in the environment, potential human receptor groups and potential exposure pathways to human receptors. The CEM or CSM may be presented in a tabular, graphical or schematic diagram format and may include a narrative description. The CEM or CSM allows interested parties to see a “snapshot” of the site, to focus attention on the critical issues, prioritize actions to be taken on the site and guide further site assessment and management actions. More information on CSMs and CEMs can be found in HC (2010) and CCME (2016).

Table 5 and Figures 1 through 4 provide examples of CEMs for the three generic exposure scenarios presented in Table 1. The CEMs do not include information regarding chemical sources or fate and transport, as this should be incorporated on a site-specific basis to develop a representative CSM for the site. The generic CEMs present a variety of activities that may occur at aquatic sites as well as associated direct contact exposure pathways for suspended and settled sediments. These may not all be applicable at every site, and the CEM or CSM developed for a given site should be tailored to the land use and conditions at that site.

3.0 EXPOSURE ASSESSMENT

3.1 Sampling Considerations

Unlike soil, sediments are associated with a surface water body and, as a result, they may be far more dynamic. Much of the fate and transport of chemicals associated with sediments are governed by this close association with water. Care should be taken to collect sediment samples that are representative of site conditions.

In general, finer particles are associated with higher contaminant concentrations than coarse-grained particles, and finer sediments are often comprised of aggregates (or flocs) of clay, organic matter and smaller amounts of sand and silt (Bright et al. 2006; Droppo et al. 1998).

For the purpose of evaluating human exposure to contaminated sediments, it is important to have adequately characterized chemical concentrations in surficial sediments at the site. The depth to which sediments should be characterized may vary depending on the types of activities people may undertake at the site, in addition to other factors.

In some circumstances (e.g. basin-wide sites), a more detailed analysis of sediment fate and transport may be considered. Please refer to the CCME Environmental Site Characterization guidance document (CCME 2016) for guidance on design and implementation of a sediment and surface water sampling program.

3.2 Estimating Exposure Point Concentrations

For deterministic exposure assessments, chemical concentrations are represented by point estimates. These point estimates may be based on the arithmetic mean, upper 95% confidence interval of the mean, 95th percentile of the data distribution, or some other statistic, depending on the quality and quantity of data available. Use of the mean or upper 95% confidence interval of the mean is preferred where sufficient data exist. However, for preliminary quantitative risk assessments (PQRAs) where data are more limited (e.g. $n < 20$), the maximum measured concentration or the 95th percentile of the data distribution is typically the most appropriate estimate of exposure point concentrations (HC 2012). For probabilistic assessments, chemical concentrations will be represented by the full distribution of the measured values at the site. Guidance on probabilistic risk assessments can be found in Health Canada (2010). Further guidance on estimating exposure point concentrations and appropriate statistical methods used in site investigations can be found in HC (2010), US EPA (2015) and CCME (2016).

3.3 Receptor characterization

Receptor characteristics for sediment exposure differ from those recommended for soil exposure. This is due to the nature of activities at aquatic sites and the greater adherence of wet sediments to skin, relative to soil. Most notably, the surface area of exposed skin, the dermal adherence (or skin surface loading) and the incidental ingestion rate for sediments are expected to be greater than for those typically assumed for soils. Default receptor characteristics are discussed below, and recommended values are provided in Tables 2, 3 and 4.

If the activities undertaken at a site differ substantially from those described in Table 1, parameters related to receptor characteristics may be modified, or exposure pathways may be excluded, provided detailed justification for all changes is included.

Note that exposure to sediment may be infrequent or short-term, (e.g. due to recreational use once a week or daily for the summer months) as opposed to continuous exposure. Therefore, exposures may be of shorter duration than those upon which most toxicological reference values (TRVs) are normally based. See section 3.5 for more information on assessing less-than-chronic or short-duration exposure scenarios.

3.3.1 Surface Areas, Body Weights and Inhalation Rates

Default assumptions for surface areas of various body parts, body weights and inhalation rates for each receptor group are summarized in Table 2.

Table 2. Default Surface Areas, Body Weights and Inhalation Rates for Human Receptors in Sediment Exposure Scenarios

Receptor Characteristics	Age Group			
	Toddler 7 mos.–4 yrs.	Child 5–11 yrs.	Teen 12–19 yrs.	Adult ≥ 20 yrs.
Surface Area (cm^2)				
Hands	430	590	800	890
Forearms[1]	450	740	1120	1250
Whole Arms	890	1480	2230	2500
Legs	1690	3070	4970	5720
Feet[2]	430	720	1080	1190
Whole Body	6130	10 140	15 470	17 640
Body Weight (kg)	16.5	32.9	59.7	70.7
Inhalation Rate (m^3/day)	8.3	14.5	15.6	16.6

Source: Health Canada (2012) unless noted otherwise.

[1] Assumed to be 50% of the whole arm surface area

[2] Richardson (1997)

The actual surface area exposed for each receptor will be site-specific, depending on how people use the site. For example, whole body exposure would typically be expected for receptors who are participating in recreational activities at a beach in the summer. In contrast, workers would typically have only partial body exposure, depending on the type of work they are doing and the type of clothing and personal protective equipment they are expected to wear.

Receptor characteristics are not provided for infants (i.e. age 0 to 6 months). This age group is expected to have minimal contact with sediments due to their developmental stage (i.e. they are typically unable to crawl or walk) and due to the expectation that typical caregiver behaviours would limit significant direct contact of infants with sediment. If infants are reasonably expected to be in direct contact with sediments at a contaminated site, receptor characteristics outlined in HC (2012) may be used to evaluate exposure.

3.3.2 Dermal Adherence Factors

Dermal adherence of sediments suspended in water is assumed to be relatively insignificant at most sites. Dermal exposure to underwater bedded sediments may need to be considered under some circumstances (e.g. where sediment contamination is limited to underwater bedded sediments and people are expected to be in direct contact with contaminated bedded sediments in shallow water). Under circumstances where dermal exposure to sediments suspended in water or to underwater bedded sediments is considered a significant pathway, careful consideration must be given to the dermal adherence factor selected for the risk assessment. At most sites, dermal exposure will likely be primarily via direct dermal contact with sediments that are periodically exposed (e.g. intertidal sediments). The focus of this section is therefore on dermal adherence (also referred to as “loading”) of sediments that are periodically exposed.

Most of the published sediment dermal adherence factors were estimated based on exposure to both exposed and suspended sediments/underwater bedded sediments. Given that the adherence of suspended sediments or underwater bedded sediments is expected to be lower than that of exposed sediments, these dermal adherence factors may overestimate dermal adherence for situations where chemicals are present only in suspended sediments or submerged bedded sediments.

Dermal adherence has been shown to increase with increasing moisture content and decreasing particle size (Spalt et al. 2009; Ruby and Lowney 2012). Therefore, dermal adherence is expected to be greatest for wet, fine-grained sediments.

As with dermal exposure to soil, receptors’ dermal exposure to sediments is assumed to occur as a single event rather than being time dependant (i.e. the same dose is assumed regardless of the time spent at the site). A single dermal exposure event would therefore occur for each day of exposure. However, dermal absorption can be affected by sediment adherence which may not be constant over time. For example, initial contact with moist sediments may result in high adherence to skin surfaces but sediments, particularly those sediments comprised of larger particle sizes, may fall off the skin as they dry, or may otherwise be removed due to subsequent movement or activity.

Risk assessors may choose to estimate dermal loading and absorption over a period of time, rather than as one event per day. This choice should be supported by a scientific rationale and justification. Currently, experimental research on adherence of particles to skin over time is lacking. As the state of the science evolves, improved methods to account for differences in adherence (i.e. super-monolayer coverage or sub-monolayer coverage for different body parts) and the effects of loading on dermal absorption may become available.

A summary of select sediment adherence factors for various body parts compiled from the literature available at time of publication is provided in Table 3; however, these papers should be consulted for further details. The values presented in Table 3 are all based on field measurements.

Risk assessment practitioners may choose to use the values presented in Table 3 or any other values that are deemed appropriate with sufficient supporting scientific rationale. A good understanding of the factors that affect dermal exposure is needed to ensure exposure estimates are realistic (i.e. not over- or underestimated) and to reduce uncertainty in dermal exposure estimates. Factors that affect dermal absorption and dermal exposure estimates can be found in Spalt et al. (2009), Kissel (2011) and Frasch et al. (2014). Risk assessment practitioners are encouraged to remain apprised of current developments in dermal exposure science to ensure that exposure estimates are realistic and to reduce uncertainty in dermal exposure estimates.

Table 3. Select Published Dermal Adherence Factors from Field Studies

Study	Shoaf et al. (2005a)			Shoaf et al. (2005b)	Kissel et al. (1996)		
Age group	Children ages 7–12 (1st exposure; 30–60 min.)	Children ages 7–12 (2nd exposure; 20–60 min.)	Children ages 7–12 (overall exposure)	Adults	Children ages 9–14 (kids-in-mud 1st exposure; 10-min. exposure)	Children ages 9–14 (kids-in-mud 2nd exposure; 20-min. exposure)	Adults
Number of participants	9	9	18	18	6	6	4
Sediment characteristics	Medium to coarse sand (9% very fine, 18% fine, 34% medium, 26% coarse, 11% very coarse; 1% clay and silt); mean OC ≈ 1%			Very fine to fine sand (29% very fine, 44% fine, 19% medium, 4% coarse; 4% clay and silt); mean OC = 0.58%	NR (material described as mud)		NR
Activity	Unscripted play in tidal flat; shoes off			Clam digging in tidal flat; shoes on*	Unscripted play in lake shoreline mud ("kids-in-mud"); shoes off		Reed gathering in tidal flat; shoes on**
Face	0.036	0.049	0.042	0.02	NR	NR	NR
Forearms	0.16	0.19	0.17	0.12	11	11	0.036
Hands	0.38	0.62	0.49	0.88	35	58	0.66
Lower legs	0.68	0.71	0.70	0.16	36	9.5	0.16
Feet	17	26	21	0.58	24	6.7	0.63

Results are presented as geometric means in mg/cm^2

NR = not reported; OC = organic carbon

Sediment particle size categories are defined as follows: clay and silt ≤ 0.0625 mm, very fine sand = 0.0625–0.124 mm, fine sand = 0.125–0.249 mm, medium sand = 0.25–0.499 mm, coarse sand = 0.5–0.999 mm, very coarse sand = 1.0–1.999 mm.

* 13 participants wore shoes, 3 wore boots, 1 wore sandals and 1 went barefoot.

** All 4 participants wore shoes but one participant lost a shoe during the study.

For comparative purposes, Bergstrom et al. (2011) present a range of dermal adherence factors for hands based on exposure to both dry (0.0605 to 1.14 mg/cm^2) and wet sediments (1.8 to 20.5 mg/cm^2) in a laboratory setting. The sediments used by Bergstrom et al. (2011) were from a variety of locations in the Pacific Northwest of the United States that had been impacted by mining and/or smelting activities. The values reported in field studies (see Table 3) are considered more reliable than those from studies in a laboratory setting. However, the dermal adherence factors reported by Bergstrom et al. (2011) are generally consistent with the range of values reported in the field studies and support a general greater adherence of wet vs. dry sediments.

Where sediment grain size and organic carbon content are generally similar to those reported in either Shoaf et al. (2005b) or Shoaf et al. (2005a), the dermal adherence factors from these studies may be appropriate for application in the HHRA. For sites where sediments are comprised of substantially finer material than reported for Shoaf (2005b) and it is not clear that these values would be sufficiently conservative, it may be appropriate to consider the more conservative values reported by Kissel et al. (1996) for kids-in-mud.

It should be noted that the dermal adherence factors reported for participants with bare feet were at least one order of magnitude greater than those reported for participants who wore shoes. Careful consideration of the exposure scenario should be given when selecting dermal adherence factors for feet. For example, the Shoaf et al. (2005a) values may be more appropriate for a scenario where people are expected to be barefooted, even if sediments at the site more closely resemble those from the Shoaf et al. (2005b) study.

Under a high-contact type scenario where full body exposure may be expected, dermal adherence factors for the torso will need to be inferred based on dermal adherence factors reported for other body parts.

It is the responsibility of the practitioner completing the HHRA to determine which adherence (i.e. loading) factors are appropriate for the site in question and to provide sufficient rationale for the values selected. Adjustments to percent coverage of body surface area can be made if scientific rationale and justification are provided.

3.3.3 Sediment Ingestion Rates

There are currently no empirically derived estimates for sediment ingestion rates. Historically, incidental soil ingestion rates have typically been used to estimate exposure to sediment. However, due to the nature of activities that may occur at some aquatic sites (picnicking on the beach, playing in shoreline sediments with limited clothing cover, etc.) and due to the anticipated increased adherence associated with a higher moisture content, incidental sediment ingestion rates may be greater than those predicted for soil.

Sediment ingestion rates for most age groups were derived by Wilson et al. (2015) using mechanistic modelling of hand-to-mouth transfer and incidental ingestion of surface water; these rates are presented in Table 4. Average daily exposure time on-site is expected to be highly variable for aquatic sites; therefore, sediment ingestion rates are presented in mg/hour to allow for adjustment for the number of hours per day spent on-site, to more accurately reflect site-specific exposure scenarios. This differs from HC (2012) guidance for soil ingestion, which is provided as mg/day. Sediment ingestion rates must be adjusted for the hours per day on-site in order to compare them directly with the soil ingestion rates, which are presented in mg/day.

The hand-to-mouth contact sediment ingestion rates are relevant for on-land activities (such as playing in the sand on a beach), where the sediment is exposed. The suspended sediment ingestion rates listed in Table 4 are relevant for near-shore in-water activities in shallow water (such as wading, walking and playing in water) where immersion in water is likely. For sites where both on-land and near-shore in-water activities are expected, the hand-to-mouth contact rates should be applied for the duration of the time spent on-site, unless the division of time between on-land and in-water activities can be clearly defined. The sediment ingestion rates may be adjusted on a site-specific basis using the approach outlined in Wilson and Meridian (2011) and Wilson et al. (2015).

In some scenarios where large areas of contaminated sediments may be found within a water body (such as a lake or harbour), and activities such as swimming or surfing that occur in deeper waters are identified as the main activities at the sediment site, it would be appropriate to estimate the exposures from these activities by using a surface water ingestion rate based on the water activity and the total contaminant concentration in surface water. Wilson et al. (2015) suggest that using total water concentrations in these scenarios would eliminate the need for assumptions regarding the suspended sediment concentration from local impacts in water bodies that have large areas of contaminated sediments. Surface water ingestion rates can be found in the literature (e.g. Dufour et al. 2006, Stone et al. 2008, Schets et al. 2011, Wilson et al. 2015); however, it is up to the HHRA practitioner to select the most appropriate sediment or surface water ingestion rates for the receptors at the site based on site activities and provide sufficient rationale to support the selections made.

Table 4. Estimated Sediment Ingestion Rates

Sediment Ingestion Rate (Probabilistic Estimate Arithmetic Means)	Age Group			
	Toddler 7 mos.–4 yrs.	**Child** 5–11 yrs.	**Teen** 12–19 yrs.	**Adult** ≥ 20 yrs.
Hand-to-Mouth Contact ($SedIR_{HM}$; on-land activities only) (mg/hour)	**72**	**57**	**18**	**20**
Suspended Sediment Contact ($SedIR_{SS}$; in-water activities only)* (mg/hour)	7.7	7.7	7.7	7.7

Source: Sediment ingestion rates are from Wilson et al. (2015).

Bold values can be considered to be an appropriate conservative estimate of overall sediment ingestion rate for the general public in frequent contact with sediments.

* Applicable to near-shore in-water activities in shallow water; does not consider high-energy environments (refer to Wilson et al. 2015)

3.4 Exposure Frequency and Duration

Exposure frequency and duration should be determined on a site-specific basis as these parameters are expected to vary substantially from site to site.

3.5 Special Considerations for Less-Than-Chronic Exposure Duration

Exposure to chemicals at an aquatic site is likely to be seasonal and intermittent rather than continuous (i.e. exposure will be less than 24 hours/day, 365 days/year). These exposure patterns are not comparable to the chronic or lifetime exposure scenarios for which most TRVs are developed.

Health effects due to less-than-chronic exposure may differ from effects resulting from chronic or lifetime exposure. As a result, evaluating health risks from short-duration exposure requires different approaches. These approaches must take into consideration several factors, including the chemical's mode of action under a specific exposure scenario of interest, and the elimination half-life of the chemical or its active metabolite. For intermittent exposures, the potential for biological effects associated with each exposure episode to accumulate during non-exposure periods also needs to be considered.

In general, dose averaging (i.e. mathematically spreading out a short-duration dose over a longer period of non-exposure) cannot be supported unless the short-duration daily exposure and the adjusted (i.e. dose averaged) daily exposure can be demonstrated to be toxicologically equivalent. Supporting analyses should be conducted on a chemical- and scenario-specific basis. Alternatively, a conservative approach of not dose averaging can be used. If no risks are identified above target levels without dose averaging, dose averaging is not necessary.

For guidance on less-than-lifetime exposures to carcinogens, please refer to HC's *Interim Guidance on Human Health Risk Assessment for Short-Term Exposure to Carcinogens at Contaminated Sites* (2013).

It should be noted that short-duration exposure to carcinogenic agents may also elicit non-cancer health effects. For carcinogenic contaminants that may elicit both non-carcinogenic and carcinogenic health effects, the potential risk of non-carcinogenic effects needs to be evaluated, in addition to risk from the carcinogenic endpoint.

Non-cancer effects from short-duration exposures can be evaluated for the most critical receptors that access a site. This includes relevant receptors/lifestages with the highest exposure and/or receptors/lifestages associated with specific sensitivity to the toxicity of the chemicals. For chemicals with non-carcinogenic effects (i.e. where the potential effect on human health is not cancer), a tiered (phased) approach to risk assessment is recommended with higher levels of toxicological expertise required, as one moves to higher-tiered assessments.

The initial screening step to assess chemicals with non-carcinogenic effects involves comparing an unadjusted daily exposure (i.e. without dose averaging and using an exposure term of “1”) to a chronic TRV (which is based on the most sensitive endpoint and lifestage, including developmental toxicity). For these substances, health effects are not anticipated if target hazard levels are not exceeded. If target hazard levels are exceeded, a more detailed evaluation (i.e. higher-tiered assessment) is required to characterize the potential for health effects since the initial tier is a conservative screening approach designed to eliminate those substances that do not need to be considered further.

For further guidance on risk assessment for less-than-chronic exposures with respect to non-carcinogenic effects (i.e. higher-tiered assessment), please consult Health Canada’s memorandum (2016).

3.6 Bioavailability

In some cases, incorporation of a relative bioavailability (RBA) adjustment may be considered for a contaminant when the environmental exposure route or medium differs from that used in the critical study upon which the toxicity reference value (TRV) for the contaminant is based. For example, exposure of the contaminant from dermal absorption can be estimated by adjusting the oral absorption of the contaminant with a relative dermal absorption factor. Relative bioavailability can also be applied in risk assessment to account for the difference in absorption between the contaminant in the environmental medium (e.g. sediment) relative to the dosing medium used in the toxicity study from which the TRV is derived. Further guidance on adjusting exposure for relative bioavailability can be found in HC (2010, 2012). Health Canada should be consulted if bioavailability adjustments are being considered.

3.7 Exposure Estimation

General equations that may be used to estimate exposure are presented in Exhibit 1. For non-threshold carcinogens acting through a mutagenic mode of action, HC (2013) should be consulted for additional guidance on the application of age-dependent adjustment factors (ADAFs) to the cancer slope factor (or inhalation unit risk) with exposure averaged over a lifetime to account for varying sensitivities of the age-specific exposure periods. The general exposure equations (Exhibit 1) will therefore need to be modified for these non-threshold carcinogens acting through a mutagenic mode of action.

3.8 Toxicity Assessment

The toxicity assessment of an HHRA involves identifying the potential toxic effects of chemicals and establishing TRVs with which to characterize potential risks. Please refer to HC (2010; 2012) for further guidance on toxicity assessment.

Exhibit 1. Recommended General Equations for Dose Estimation

Generalized equations are presented below; actual equations presented by individual contractors may vary according to the manner in which different variables are presented, the units used, and the exposure frequency, exposure duration, and averaging times used in the exposure scenarios. Abbreviations denoting variables have been harmonized through all equations.

Inadvertent Ingestion of Contaminated Sediment

The predicted intake of each contaminant via ingestion of contaminated sediment is calculated as:

$$\text{Dose (mg/kg bw/day)} = \frac{C_s \times SedIR \times RAF_{Oral} \times D_1 \times D_2 \times D_3 \times D_4 \times CF}{BW \times LE}$$

Where:

C_S = concentration of contaminant in sediment (mg/kg)
SedIR = receptor sediment ingestion rate (mg/hr)
RAF_{Oral} = relative absorption factor from the gastrointestinal tract (unitless)
D_1 = hours per day
D_2 = days per week exposed/7 days
D_3 = weeks per year exposed/52 weeks
D_4 = total years exposed to site (to be employed for assessment of carcinogens only)
CF = conversion factor of 1 kg/1 000 000 mg
BW = body weight (kg)
LE = life expectancy (years) (to be employed for assessment of carcinogens only)

Note: D_1, D_2, D_3 and D_4 should be evaluated on a chemical-specific basis. Any dose averaging applied in the risk assessment should be accompanied by supporting scientific rationale on a chemical-specific basis.

Inhalation of Airborne Particulates

$$\text{Dose (mg/kg bw/day)} = \frac{C_s \times P_{Air} \times IR_A \times RAF_{Inh} \times D_1 \times D_2 \times D_3 \times D_4}{BW \times LE}$$

Where:

C_S = concentration of contaminant in sediment (mg/kg)
P_{Air} = particulate concentration in air (kg/m^3)
IR_A = receptor air intake (inhalation) rate (m^3/day)
RAF_{Inh} = relative absorption factor by inhalation (unitless)
D_1 = hours per day exposed/24 hours
D_2 = days per week exposed/7 days
D_3 = weeks per year exposed/52 weeks
D_4 = total years exposed to site (to be employed for assessment of carcinogens only)
BW = body weight (kg)
LE = life expectancy (years) (to be employed for assessment of carcinogens only)

Note: P_{Air} may be directly measured or may be estimated using methods discussed Section 2.5.5 of Health Canada (2012). Alternately, the airborne concentration (mg/m^3) ($C_A = C_s \times P_{Air}$) may be directly measured, negating the prediction of airborne concentration using C_S and P_{Air}. D_1, D_2, D_3 and D_4 should be evaluated on a chemical-specific basis. Any dose averaging applied in the risk assessment should be accompanied by supporting scientific rationale on a chemical-specific basis.

Dermal Absorption from Contaminated Sediment

The predicted intake of each contaminant via dermal contact with contaminated sediment is calculated as:

$$\text{Dose (mg/kg bw/day)} = \frac{C_s \times [\sum(SA_i \times SL_i)] \times RAF_{Derm} \times D_2 \times D_3 \times D_4}{BW \times LE}$$

Where:

C_S = concentration of contaminant in sediment (mg/kg)
SA_i = surface area of body part i exposed for sediment loading (cm^2)
SL_i = sediment loading rate to exposed skin of body part *i* (kg/cm^2-event)
RAF_{Derm} = relative dermal absorption factor (unitless)
D_2 = days per week exposed/7 days
D_3 = weeks per year exposed/52 weeks
D_4 = total years exposed to site (for assessment of carcinogens only)
BW = body weight (kg)
LE = life expectancy (years) (for assessment of carcinogens only)

Note: D_2, D_3 and D_4 should be evaluated on a chemical-specific basis. Any dose averaging applied in the risk assessment should be accompanied by supporting scientific rationale on a chemical-specific basis.

4.0 RISK CHARACTERIZATION

Risk characterization is the estimated risk or hazard resulting from exposure to chemicals from a contaminated site. Potential risks are assessed for a given chemical by comparing the estimated exposure from the site with the appropriate TRV. Further guidance on risk characterization can be found in HC (2010; 2012).

4.1 Uncertainty and Variability

A discussion on uncertainty and variability should be included in the risk characterization section of the risk assessment. Generally, the similarities between soil and sediment are enough to justify the use of the same methodology for estimating oral and dermal exposure, but there are several factors that can affect oral and dermal exposure estimates. Factors that can affect exposure estimates include time spent at the site (i.e. frequency and duration of visits) and activities while at the site. Sediment adherence and dermal absorption can be affected by sediment characteristics such as particle size, organic carbon content and moisture content. Sediment loading and percent coverage of body surface area (which may not be constant over time), chemical specific properties and the methodology used to derive absorption values can all contribute to uncertainty and variability in exposure estimates. These factors contribute to difficulty in establishing typical exposure parameters for sediment sites.

Modifications can be made to input parameters used in the exposure estimates to better characterize human health risks at sediment sites on a site-specific basis; however, justification for any of these modifications should be provided in the risk assessment and the uncertainties inherent with the approach chosen should be discussed in the risk characterization. It is important that the risk assessor be able to communicate the uncertainty and variability (and degree of confidence) associated with the risk estimates, so they can be adequately considered in the decision-making process for any further action at the contaminated site. More details on assessment of uncertainty and variability in risk assessments are provided in HC (2010).

5.0 EXAMPLES OF CONCEPTUAL EXPOSURE MODELS FOR DIRECT EXPOSURE TO SEDIMENT

Table 5. Example of Conceptual Exposure Model in Table Format

Exposure Medium	Exposure Pathway					Receptors
	Inhalation of Dust/Airborne Particulate	Incidental Ingestion of Sediment	Dermal Contact with Sediment	Incidental Ingestion of Sediment Suspended in Water	Vapour Inhalation	
Shoreline Intertidal Sediment and/or Wetlands	✓	✓	✓		✓	General Population (all ages)
Near-Shore Sediment (shallow)			✓*	✓		General Population (all ages)
Offshore Sediment (deep)				✓		Worker (adults)

* Dermal contact with suspended and bedded sediment in the shallow near-shore zone would typically be relatively insignificant in comparison to dermal contact with exposed sediment. However, under certain circumstances this pathway may need to be considered (refer to Section 2.4).

Figure 1. Example of Conceptual Exposure Model in Flow Chart Form

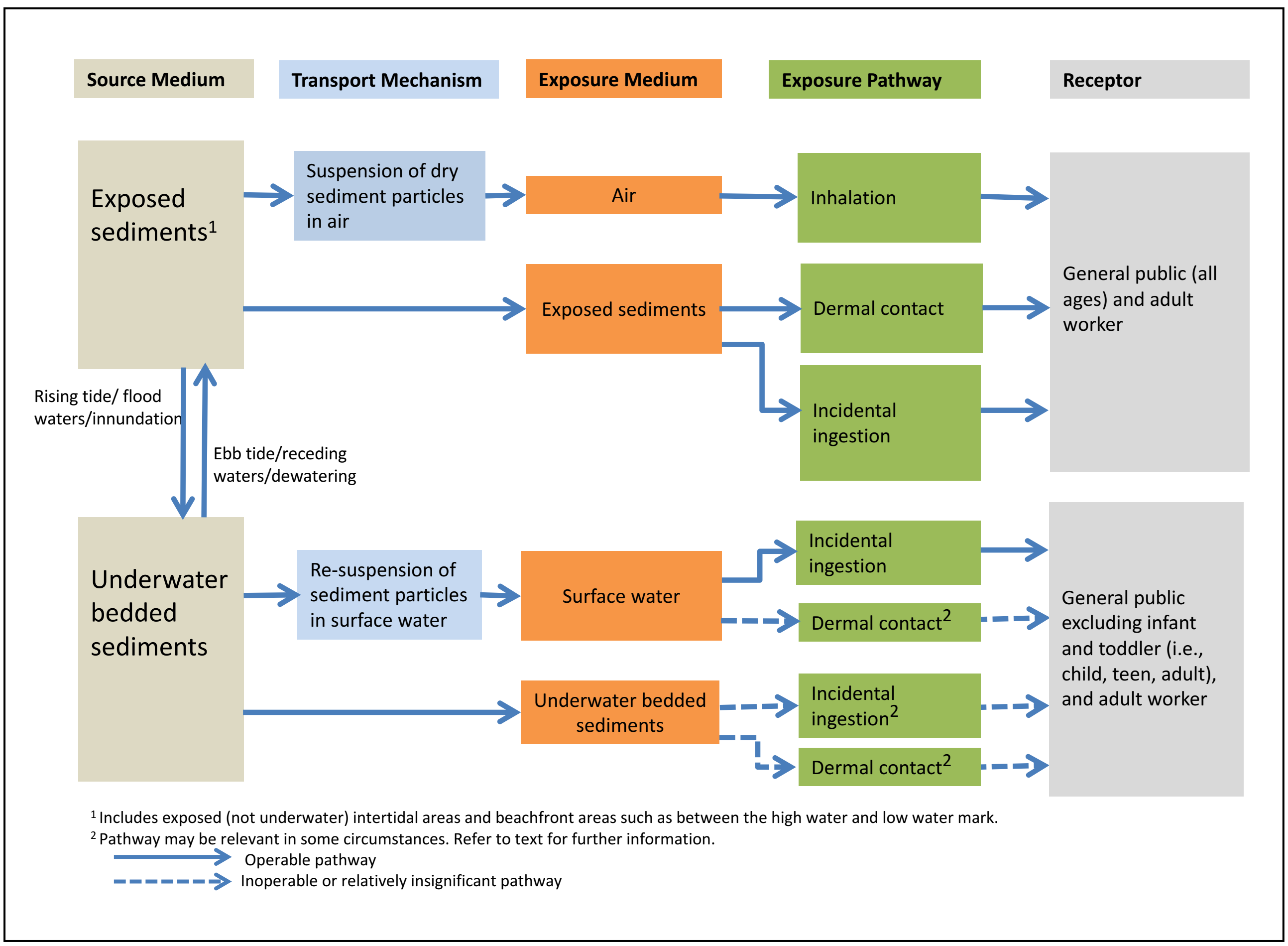


Figure 2. Example of Conceptual Exposure Model for Recreational Low-Contact Sediment Site

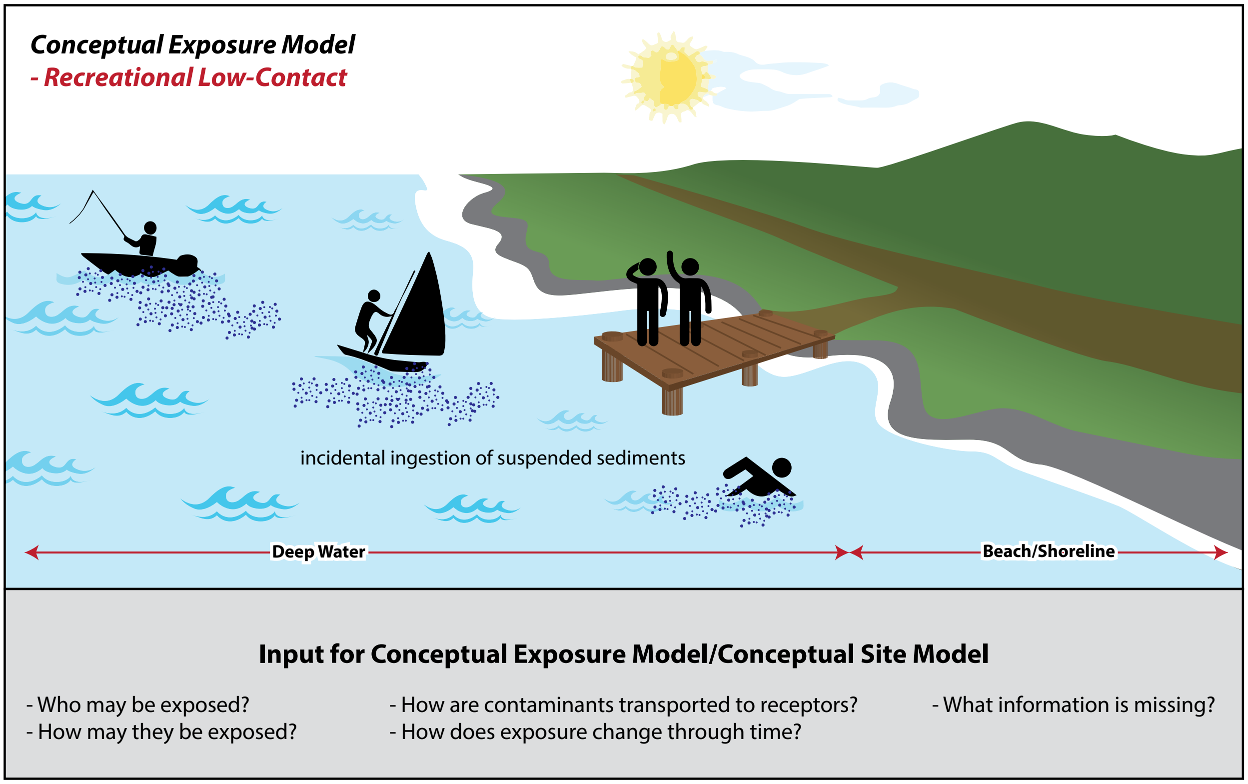
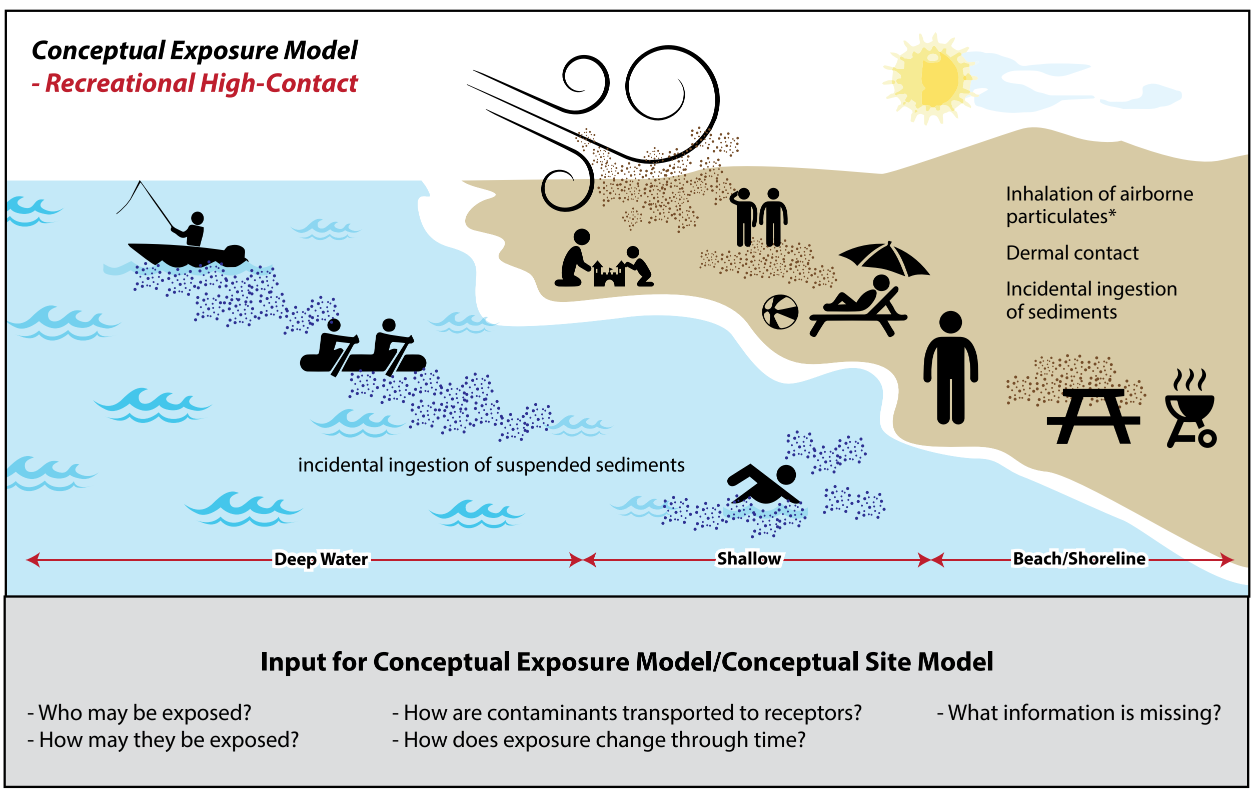
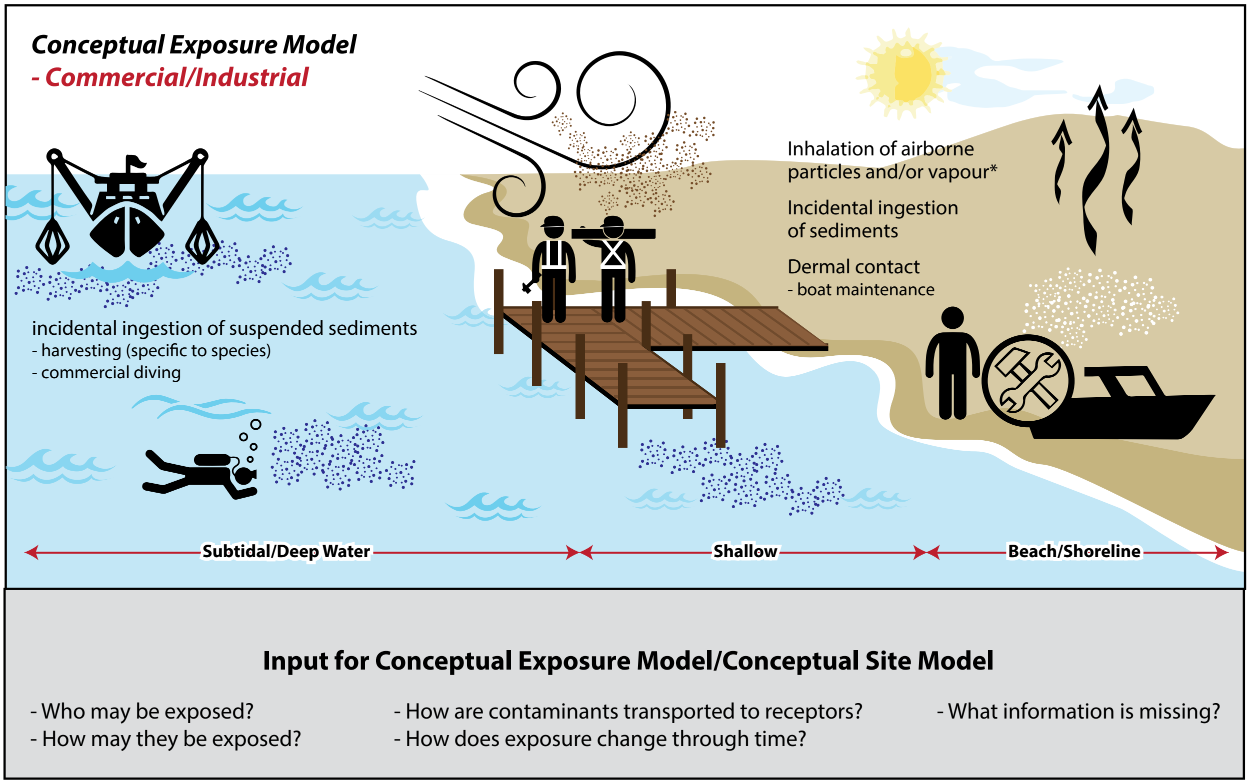


Figure 3. Example of Conceptual Exposure Model for Recreational High-Contact Sediment Site



* Only relevant where sediments dry out periodically

Figure 4. Example of Conceptual Exposure Model for Commercial/Industrial Sediment Site



* Only relevant where sediments dry out periodically

6.0 REFERENCES

Bergstrom C, J Shirai, J Kissel. 2011. Particle Size Distributions, Size Concentration Relationships, and Adherence to Hands of Selected Geologic Media Derived from Mining, Smelting, and Quarrying Activities. Sci. Total Environ. 409(20):4247–4256.

Bright, DA, GM Richardson, M Dodd. 2006. Do Current Standards of Practice in Canada Measure What is Relevant to Human Exposure at Contaminated Sites? I: A Discussion of Soil Particle Size and Contaminant Partitioning in Soil. Hum. Ecol. Risk. Assess. 12(3):591–605.

CCME (Canadian Council of Ministers of the Environment). 1995. Protocol for the Derivation of Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment. CCME EPC-98E. http://ceqg-rcqe.ccme.ca/download/en/226

CCME. 2016. Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment, Volume 1–4, Canadian Council of Ministers of the Environment, Winnipeg.

Droppo, IG, DE Walling, ED Ongley. 1998. Suspended Sediment Structure: Implications for Sediment and Contaminant Transport Modelling. *Modelling Soil Erosion, Sediment Transport and Closely Related Hydrological Processes* (Proceedings of a symposium held at Vienna, July 1998). IAHS Publ. no. 249.

Dufour, AP, O Evans, TD Behymer, R Cantú. 2006. Water ingestion during swimming activities in a pool: A pilot study. J. of Water Health 4:425-430.

EC (Environment Canada). 2010. Pulp and Paper Environmental Effects Monitoring (EEM) Technical Guidance Document. Available at: www.ec.gc.ca/esee-eem/default.asp?lang=En&n=3E389BD4-1

FCSAP (Federal Contaminated Sites Action Plan). 2010a. Federal Contaminated Sites Action Plan (FCSAP): Ecological Risk Assessment Guidance. Module 1: Toxicity Test Selection and Interpretation. Prepared by Golder Associates Ltd under contract to Environmental Stewardship Branch, Environment Canada, Vancouver, March 2010.

FCSAP. 2010b. Federal Contaminated Sites Action Plan (FCSAP): Ecological Risk Assessment Guidance. Module 2: Selection or Development of Site-Specific Toxicity Reference Values. Prepared by Azimuth Consulting Group Inc. under contract to Environmental Stewardship Branch, Environment Canada, Vancouver, June 2010.

FCSAP. 2012a. Federal Contaminated Sites Action Plan (FCSAP): Ecological Risk Assessment Guidance. Prepared by Azimuth Consulting Group under contract to Environmental Stewardship Branch, Environment Canada, Vancouver, March 2012.

FCSAP. 2012b. Federal Contaminated Sites Action Plan (FCSAP): Ecological Risk Assessment Guidance. Module 3: Standardization of Wildlife Receptor Characteristics. Prepared by Azimuth Consulting Group Inc. under contract to Environmental Stewardship Branch Environment Canada, Vancouver, March 2012.

FCSAP. 2013. Federal Contaminated Sites Action Plan (FCSAP): Ecological Risk Assessment Guidance. Module 4: Causality Assessment. Determining the Causes of Impairment at Contaminated Sites: Are Observed Effects Due to Exposure to Site-Related Chemicals or Due to Other Stressors? Prepared by Environ International Corporation under contract to Fisheries and Oceans Canada, March 2013.

FCSAP. In preparation. "Ecological Risk Assessment Guidance Module 5: Defining Background Conditions and Using Background Concentrations".

Frasch, HF, GS Dotson, AL Bunge, C Chen, JW Cherrie, GB Kasting, JC Kissel, J Sahmel, S Semple and S Wilkinson. 2014. Analysis of finite dose dermal absorption data: Implications for dermal exposure assessment. J. Expo. Sci. Environ. Epidemiol. 24:65-73. Doi: 10.1038/jes.2013.23

HC (Health Canada). 2010. Federal Contaminated Site Risk Assessment in Canada, Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals ($DQRA_{Chem}$). Contaminated Sites Division, Safe Environments Directorate, Ottawa.

HC. 2012. Federal Contaminated Site Risk Assessment in Canada, Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA), Version 2.0. Contaminated Sites Division, Safe Environments Directorate, Ottawa.

HC. 2013. Federal Contaminated Site Risk Assessment in Canada: Interim Guidance on Human Health Risk Assessment for Short-Term Exposure to Carcinogens at Contaminated Sites. Contaminated Sites Division, Safe Environments Directorate, Ottawa.

HC, 2016. Memorandum: A Primer for Evaluating Human Health Risk at Contaminated Sites for Chronic and Less-Than-Chronic Exposures to Chemicals (October 2016). Contaminated Sites Division, Safe Environments Directorate, Ottawa.

Kissel JC, KC Richter, RA Fenske. 1996. Field Measurement of Dermal Soil Loading Attributable to Various Activities: Implications for Exposure Assessment. Risk Anal. 16(1):115–125.

Kissel JC. 2011. The mismeasure of dermal absorption. J. Expo. Sci. Environ. Epidemiol. 21: 202–309.

NY DEC (New York State Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources). 1999. Technical Guidance for Screening Contaminated Sediments – Change Sheet for January 25, 1999. Available at: www.lm.doe.gov/cercla/documents/rockyflats_docs/SW/SW-A-006230.pdf

Richardson, GM. 1997. Compendium of Canadian Human Exposure Factors for Risk Assessment. Ottawa: O'Connor Associates Environmental Inc.

Ruby MV, YW Lowney. 2012. Selective Soil Particle Adherence to Hands: Implications for Understanding Oral Exposure to Soil Contaminants. Environ. Sci. Technol. 46:12759–12771.

Schets, FM, JF Schijven, AM de Roda Husman. 2011. Exposure assessment for swimmers in bathing waters and swimming pools. Water Res, 45:2392–2400.

Shoaf MB, JH Shirai, G Kedan, J Schaum, JC Kissel. 2005a. Child Dermal Sediment Loads following Play in a Tide Flat. J. Expo. Anal. Environ. Epidemiol. 15(5):407–412.

Shoaf MB, JH Shirai, G Kedan, J Schaum, JC Kissel. 2005b. Adult Dermal Sediment Loads following Clam Digging in Tide Flats. Soil Sed. Contam. 14(5):463–470.

Spalt EW, JC Kissel, JH Shirai, AL Bunge. 2009. Dermal Absorption of Environmental Contaminants from Soil and Sediment: A Critical Review. JESEE. 19:119–148.

Stone, DL, AK Harding, BK Hope, S Slaughter-Mason. 2008. Exposure Assessment and Risk of Gastrointestinal Illness Among Surfers. J. Toxicol Environ Health, Part A: Current Issues. 71(24):1603–1615.

US EPA (United States Environmental Protection Agency). 2015. ProUCL Version 5.1 User Guide. Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations. US Environmental Protection Agency, Office of Research and Development, Washington, DC. September 2015. Available at: www.epa.gov/sites/production/files/2016-05/documents/proucl_5.1_user-guide.pdf

WADOE (Washington State Department of Ecology). 2013. Sediment Management Standards Chapter 173–204 WAC. Available at: https://fortress.wa.gov/ecy/publications/publications/1309055.pdf

WADOE. 2015. Sediment Cleanup Users Manual II. Guidance for Implementing the Cleanup Provisions of the Sediment Management Standards, Chapter 173–204 WAC. March 2015. Available at: https://fortress.wa.gov/ecy/publications/publications/1209057.pdf

Wilson Scientific and Meridian. 2011. Development of Sediment Ingestion Rates for Use in Human Health Based Sediment Quality Guidelines and Contaminated Sites Human Health Risk Assessment. Prepared by Wilson Scientific Consulting Inc. and Meridian Environmental Inc. under contract to Contaminated Sites Division, Environmental Health Programs Directorate, Health Canada.

Wilson, R, H Jones-Otazo, S Petrovic, M Roushorne, L Smith-Munoz, D Williams, I Mitchell. 2015. Estimation of Sediment Ingestion Rates based on Hand-to-Mouth Contact and Incidental Surface Water Ingestion. Hum. Ecol. Risk. Assess. 21(6):1700–1713.