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An Evaluation of the 2008 National Classification System for Contaminated Sites

by

Ronald James Thiessen

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Abstract

The ability of the 2008 National Classification System for Contaminated Sites (NCSCS) to approximate human health and ecological risk assessment results is investigated by comparing NCSCS scores against cumulative hazard indices for 8 biological receptors. Publicly available information on 20 contaminated sites located across Canada is used to conduct this analysis. NCSCS scores are positively correlated with cumulative hazard indices for some biological receptors but there is significant data scatter. Reorganising the NCSCS to have a similar structure as a risk assessment is recommended to reduce this scatter. Using the same contaminated site information, a cross analysis of human health and ecological risk assessment cumulative hazard indices is also performed to determine whether one receptor can act as a surrogate for other receptors. Based on the data, humans are the preferred surrogate for plants & soil invertebrates, cows, meadow voles, masked shrew, American kestrel, and aquatic life under defined circumstances.

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Also, I thank the Department of Civil Engineering for reimbursing costs associated with this research and for nominating me for the Queen Elizabeth II Graduate Scholarship. This support is appreciated.

Finally, I thank Dr. Gopal Achari for his encouragement to pursue a graduate degree, his guidance when the research objectives seemed fuzzy, and for his patience as I completed research while working full time.

Dedication

This work is dedicated to my dad, Art Thiessen, because he exemplifies perseverance despite adversity. I also dedicate this work to my best friend, Rhonda, and our children, Aaron, William, and Ava. Thank you for your encouragement when I needed it. I love you all.

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List of Symbols & Abbreviations

Symbol or Abbreviation	Definition
AB	Alberta
$aveCI_{eco}$	geometric mean of CI_k value for ecological receptors
AENV	Alberta Environment
AF_e	proportion of time receptor is at contaminated site
AF_{fr}	proportion of receptor's foraging range
AF_G	human gastrointestinal tract absorption factor
AF_L	human lung absorption factor
AF_S	human skin absorption factor
Agri	agricultural land use
AST	aboveground storage tank
B_b	biotransfer factor from vegetation to beef
B_m	biotransfer factor from vegetation to milk
BC	British Columbia
BF	contaminant bioavailability factor
BTEX	benzene, toluene, ethylbenzene, & xylenes
BW or bw	body weight
°C	Celsius
C	measured contaminant concentration in soil, water, or food
C_a	contaminant concentration in soil vapour
$C_{a,gw}$	contaminant concentration in soil vapour immediately above impacted groundwater
$C_{a,indoor}$	contaminant concentration in indoor air
$C_{a,max}$	maximum contaminant concentration in soil vapour based on pure phase vapour pressure
$C_{a,soil}$	contaminant concentration in soil vapour due to contaminants adsorbed to soil particles
C_b	contaminant concentration in beef
C_l	contaminant concentration in soil leachate
$C_{l,gw,ave}$	area weighted average of $C_{l,gw,i}$
$C_{l,gw,i}$	contaminant concentration in soil leachate at cell i before mixing with ambient groundwater
C_m	contaminant concentration in milk
C_p	contaminant concentration in dry produce or plants
C_{part}	particulate bound contaminant concentration in ambient air
C_{pm}	particulate matter concentration in ambient air
C_s	contaminant concentration in soil
$C_{s,max}$	contaminant concentration in soil at equilibrium with the contaminant's effective solubility
C_{shrew}	contaminant concentration in masked shrew
C_t	total contaminant concentration in soil matrix
C_{ts}	contaminant concentration in topsoil
C_w	contaminant concentration in water

Symbol or Abbreviation	Definition
C_{wind}/Q_{pm}	normalised annual average particulate matter concentration
C_{worm}	contaminant concentration in earthworms
CCME	Canadian Council of Ministers of the Environment
CHC	chlorinated hydrocarbon
CI	cumulative hazard index
$CI_{i,k}$	cumulative hazard index at cell i for receptor k
CI_k	maximum cumulative hazard index for receptor k
CLSR	Canada Lands Survey Records
Com	commercial land use
COPC	contaminant of potential concern
CSM	conceptual site model
D_a	molecular diffusion coefficient in air
D_w	molecular diffusion coefficient in water
DDT	dichlorodiphenyltrichloroethane
dw	dry weight
ESA	environmental site assessment
FCSAP	Federal Contaminated Site Action Plan
FCSI	Federal Contaminated Site Inventory
FIR	food ingestion rate
$F(x)$	function dependent on U_m/U_t
H'	dimensionless Henry's constant
HALO	Britain's Hazard Assessment of Landfill Operations
$HI_{i,k,m}$	hazard index at cell i for receptor k via exposure route m
HQ	hazard quotient
$HQ_{i,j,k,m}$	hazard quotient at cell i, for contaminant j, and receptor k via exposure route m
HRS	United States' Hazard Ranking System
I	precipitation infiltration rate
Ind	industrial land use
IR	soil, water, or food ingestion rate
IR_a	air inhalation rate
$i_{\theta,r}$	cell location based on polar coordinates
k_1 ,k_2, k_3	bioaccumulation constants for plants and produce
k_4 ,k_5, k_6	bioaccumulation constants for earthworms and small mammals
K	Kelvin
K_d	distribution coefficient
K_{oc}	organic carbon partitioning coefficient
$kn,aveCI_{eco}$	geometric mean of ecological receptor cumulative hazard indices under known scenario
$knCI_{aquatic}$	maximum cumulative hazard index for aquatic life under known scenario
$knCI_{cow}$	maximum cumulative hazard index for cows under known scenario
$knCI_{human}$	maximum cumulative hazard index for humans under known scenario
$knCI_k$	maximum cumulative hazard index for receptor k under known scenario

Symbol or Abbreviation	Definition
$knCI_{kestrel}$	maximum cumulative hazard index for American kestrel under known scenario
$knCI_{micro}$	maximum cumulative hazard index for soil microorganisms (microbes) under known scenario
$knCI_{plant}$	maximum cumulative hazard index for plants & soil invertebrates under known scenario
$knCI_{vole}$	maximum cumulative hazard index for meadow voles under known scenario
$knCI_{shrew}$	maximum cumulative hazard index for masked shrew under known scenario
LPL	lower prediction limit
M_w	molecular weight
MB	Manitoba
mbg	metres below grade
Mid	midpoint value
$modS_{site}$	modified NCSCS site score
n	number in sample
N	north
Nat	natural area land use
NB	New Brunswick
NCSCS	National Classification System for Contaminated Sites
NRC	United States National Research Council
NT	Northwest Territories
NU	Nunavut Territory
ON	Ontario
p_v	vapour pressure
PAH	polycyclic aromatic hydrocarbon
Park.	parkland land use
PCB	polychlorinated biphenyl
PDI	predicted daily intake
PDI_{Ing}	predicted daily intake via ingestion
PE	Prince Edward Island
PHC	petroleum hydrocarbon
$po,aveCI_{eco}$	geometric mean of ecological receptor cumulative hazard indices under potential scenario
$poCI_{aquatic}$	maximum cumulative hazard index for aquatic life under potential scenario
$poCI_{cow}$	maximum cumulative hazard index for cows under potential scenario
$poCI_{human}$	maximum cumulative hazard index for humans under potential scenario
$poCI_k$	maximum cumulative hazard index for receptor k under potential scenario
$poCI_{kestrel}$	maximum cumulative hazard index for American kestrel under potential scenario
$poCI_{micro}$	maximum cumulative hazard index for soil microorganisms (microbes)

Symbol or Abbreviation	Definition
	under potential scenario
$poCI_{plant}$	maximum cumulative hazard index for plants & soil invertebrates under potential scenario
$poCI_{vole}$	maximum cumulative hazard index for meadow voles under potential scenario
$poCI_{shrew}$	maximum cumulative hazard index for masked shrew under potential scenario
PQRA	preliminary quantitative risk assessment
PSdC	measured or predicted contaminant concentration in sediment
PSoC	measured or predicted contaminant concentration in soil
PWC	measured or predicted contaminant concentration in water
r	radius
r_p	Pearson product moment correlation coefficient
Resi	residential land use
RPD	relative percent difference
RSD	relative standard deviation
S	pure phase aqueous solubility
S_{con}	NCSCS contaminant characteristics score
S_e	effective aqueous solubility
S_{exp}	NCSCS exposure score
S_{mig}	NCSCS migration potential score
S_{site}	NCSCS site score
SIR	soil ingestion rate
SK	Saskatchewan
t	*t* statistic
t_α	critical *t* statistic
$t_{1/2s}$	biodegradation half life in saturated soil
$t_{1/2us}$	biodegradation half life in unsaturated soil
TDI	tolerable daily intake
TSdC	tolerable contaminant concentration in sediment
TSoC	tolerable contaminant concentration in soil
TWC	tolerable contaminant concentration in water
U_m	mean annual wind speed
U_t	equivalent erosion threshold wind speed at 7 m above surface
UPL	upper prediction limit
USEPA	United States Environmental Protection Agency
UST	underground storage tank
V	fraction of ground surface covered by vegetation
W	west
w_{con}	weighting factor for NCSCS contaminant characteristic score
w_{exp}	weighting factor for NCSCS exposure score
w_i	distance interval between a cell's upper and lower bound along a given direction
w_{mig}	weighting factor for NCSCS migration potential score

Symbol or Abbreviation	Definition
Wat	waterbody or watercourse
WIR	water ingestion rate
X	contaminant mole fraction in a mixture
YT	Yukon Territory
α	Type 1 error probability
α_{gw}	groundwater contaminant attenuation factor
α_{us}	soil leachate attenuation coefficient
α_{vap}	soil vapour attenuation factor
θ	cardinal or ordinal direction (e.g., N, NE, E,...)
θ_a	air filled porosity
θ_w	water filled porosity
ρ_b	soil bulk density in vadose zone

Chapter One: Introduction

1.1 Background

Prioritizing risk management activities in a portfolio of many contaminated sites is a necessity for decision makers having limited financial resources. Decision support tools are needed to justify budget and resource allocations for the investigation and remediation of these sites. Decision makers require tools that are logical and transparent to ensure decisions are defensible and understandable to stakeholders.

The Government of Canada defines a contaminated site as "one at which substances occur at concentrations (1) above background (normally occurring) levels and pose or are likely to pose an immediate or long term hazard to human health or the environment, or (2) exceed levels specified in policies and regulations" (TBCS 2005). The Treasury Board of Canada Secretariat maintains a Federal Contaminated Site Inventory (FCSI), which is a database of contaminated sites in Canada that are the responsibility of various federal departments, agencies, and crown corporations. There are over 19,000 contaminated sites listed in the FCSI and approximately 8,000 of these sites have been classified using the National Classification System for Contaminated Sites (NCSCS), or a variant of it, published by the Canadian Council of Ministers of the Environment (CCME). Using the NCSCS and sufficient site data, sites are placed into one of four classes: Class 1 – High Priority for Action, Class 2 – Medium Priority, Class 3 – Low Priority, and Class N – Not a Priority (CCME 2008c). This classification allows the federal government to prioritise its spending in managing identified contaminated sites.

1.2 Thesis Purpose

Suter (2007) states: "Scoring systems have been used for decades to rank the risks from chemicals or from more diverse sets of agents… However, to serve as screening tools, these systems should be calibrated to actual risks so that the total score is at least roughly linearly related to risk and cut off scores can be defined for the screening categories. If scoring systems are subjective (i.e. not calibrated), it is important to avoid giving an impression of scientific accuracy to the numeric results." The context in which Suter made this statement was a discussion of scoring systems for the screening of chemicals and other agents of concern, but the concept can be extended to scoring systems for classifying contaminated sites.

The NCSCS is a tool that is useful in screening a large set of contaminated sites into groups based on known and potential risks to human and ecological health. However, the validity of CCME's assertion that its classification system is a "scientifically defensible method" (1992, 2008c) should be evaluated. A detailed description of the NCSCS is provided later on in the thesis.

1.3 Thesis Goal and Objectives

The thesis goal is to evaluate the current NCSCS published by CCME (2008c) and to propose practical enhancements to the system, as necessary, yet retain its existing simplicity. To support this goal, four research objectives are proposed:

- review the motivation and development history of the NCSCS;
- evaluate the performance of the NCSCS against a rigorous risk assessment protocol;
- identify possible weakness within the NCSCS; and,

- provide practical suggestions to improve the NCSCS as may be necessary to align it with the results of a risk assessment approach.

1.4 Thesis Organization

The organization of this thesis is based on the four objectives defined above. Chapter 1 provides an overview of the problem, thesis goals and objectives and organization.

Chapter 2 is a literature review that begins by summarizing the development history of the NCSCS from its inception in 1990 until 2008 and discusses the reasons why it changed over time. Other researchers' work related to the NCSCS is also discussed. This chapter also includes a description of how contaminated sites are scored using the current NCSCS. A discussion of risk assessment, risk assessment guidance documents, and methods to combine human health and ecological risk assessment results is provided.

Chapter 3 is a methods discussion chapter where the rationale for the chosen risk assessment protocol is justified, the protocol's details presented, and the process of comparing the NCSCS to this protocol is explained. This chapter also explains how actual contaminated sites were chosen for the comparison.

Chapter 4 provides an overview of the data associated with each selected contaminated site that was used to develop a standardised conceptual site model (CSM) for each site. Only an overview, and not all details, is provided because of the large volume of data referenced in this research. For details, the reader is directed to the publicly available source reports, which are listed in the references.

Chapter 5 is a cross analysis of human health risk assessment and ecological risk assessment results for contaminated sites to examine how they are related and assess whether one receptor can act as a surrogate for all other receptors. Chapter 6 is an investigation of the 2008 NCSCS' ability to emulate preliminary human health and ecological risk assessment results for contaminated sites. Both Chapters 5 and 6 are structured as standalone journal articles meaning there is some necessary repetition of background, methods, and information presented in Chapters 2 to 4.

Chapter 7 provides conclusions directly related to the thesis goal and objectives as well as recommendations for further research.

The Appendix contains correspondence with federal institutions related to *Access to Information Act* requests, a summary of risk assessment parameters used in this research, and tables of risk assessment results & NCSCS scores.

Chapter Two: Literature Review

2.1 NCSCS Development History

2.1.1 Original NCSCS

Energy Pathways Inc. (1991) prepared a report that summarises the motivation and context for the NCSCS' development: "The National Contaminated Sites Remediation Program…was initiated in April of 1989 by the Canadian Council of Ministers of the Environment [CCME] in response to a recognised need for a consistent approach to remediation of contaminated sites in Canada". One of the objectives of the program was "the establishment of an effective and nationally consistent approach to the identification, assessment, and remediation… of all contaminated sites in Canada that have an impact on, or have the potential for impact on, human health or the environment" (*ibid*). CCME hosted a consultation workshop with representatives from government, the public, and industry to discuss contaminated site classification along with other topics. A recommendation from the workshop was:

> "…the site classification system should: determine site priority based on assessment of primarily existing information; be broadly applicable and flexible; be based on consideration of 'risk' factors; address both hazards to human health and the environment; and be capable of assessing sites despite information gaps that may exist" (TDM 1990).

Available classification systems developed by various Canadian provinces, the United States Environmental Protection Agency, and the United Kingdom were assessed. Some classification systems assessed required information that was not readily available for most sites and that other systems were subjective because significant assessor judgement was required to classify sites. All of the classifications systems assessed

categorised contaminated sites as low, medium, or high priority for remedial action and the majority of the Canadian provinces and territories used additive scoring systems to assess sites (TDM 1990).

A classification system proposed by Trow, Dames & Moore (TDM) was presented in November 1990 at a second stakeholder workshop where formatting changes were recommended to make the evaluation form easier to use (TDM 1990). The classification system format was revised accordingly and published in March 1992 by CCME as the National Classification System for Contaminated Sites (NCSCS). The goal of the classification system was to provide a defensible method to identify high risk contaminated sites requiring remediation or risk management funding (CCME 1992). The purpose of the NCSCS was to evaluate the current or potential human and ecological impacts posed by a contaminated site without going through the details of a quantitative risk assessment (*ibid*).

CCME (1992) provides detailed user guidance for this classification system. Briefly, the system allows an assessor to categorise a contaminated site by first assigning scores to each of 37 evaluation factors divided among each of the following three site characteristic categories: contaminant characteristics, exposure pathways, and receptors. In cases where there was insufficient information to assign a factor score, the assessor was instructed to use an estimated score equal to one half of the maximum allowable score for the factor. This estimated score was considered an uncertain value. Once scores were assigned to each evaluation factor the assessor was then instructed to add the factor scores within each category to calculate category scores. The results could range up to maximums of 33, 33, and 34 for the contaminant characteristics, exposure pathways, and

receptors site characteristic categories, respectively. The scores for each site characteristic category were then summed to yield an overall site score ranging up to 100.

CCME (1992) states that the site scores should not be used to rank contaminated sites but instead used to determine which of four classes each site belongs, given sufficient site data. The defined relationships between site score and classes were as follows:

- Score is 70 to 100: Class 1 – Action Required;
- Score is 50 to 69.9: Class 2 – Action Likely Required;
- Score is 37 to 49.9: Class 3 – Action May be Required; and,
- Score is <37: Class N – Action Not Likely Required.

If the uncertain score is greater than or equal to 15, the site is categorised as Class I, which denotes "insufficient information" is present to classify the site.

2.1.2 Arsenault's Review

Arsenault (1995) assessed the 1992 NCSCS and the following contaminated site classification systems with the purpose of recommending a preferred system for the Province of Manitoba in ranking contaminated sites within its responsibility:

- United States' Hazard Ranking System (HRS);
- Britain's Hazard Assessment of Landfill Operations (HALO);
- Ontario's Waste Disposal Classification Scheme (ON System);
- New Brunswick's Assessment and Classification of Waste Disposal sites for Closure Planning (NB System); and,
- Quebec's Management of Contaminated Sites for Quebec (QC System).

Arsenault identified these systems by interviewing 17 environmental professionals from across Canada including a few individuals in the United States and the United Kingdom. Through these discussions, Arsenault established seven evaluation criteria to assist in classification system selection:

- classification factors should be based on existing information;
- environmental and human health concerns should be addressed;
- the system should be flexible enough to rank many different sites;
- the system should be straight forward to use;
- the system should be time and cost efficient;
- the system should rank sites relative to one another; and,
- the system should provide for consistent interpretation of results.

Using these criteria, Arsenault asked the same professionals for their general opinions regarding the NCSCS and its benefits and problems relative to the remaining classification systems. He compiled their responses and prepared a summary table similar to Table 2-1 that compared each system to the identified criteria. The result was a qualitative, subjective assessment of the merits of the NCSCS relative to other systems in use at that time. Arsenault concluded that of the six systems reviewed, the NCSCS met the criteria most completely and should be used by government and industry to classify contaminated sites in Manitoba. Regarding the sixth criterion that the system should rank sites relative to one another, Arsenault acknowledged that the NCSCS is not designed for site to site ranking but nonetheless considered it to be the best ranking tool of the six he investigated. Additional justification for this opinion was not provided.

He also recommended that the NCSCS be modified to meet the specific needs in Manitoba and proposed combining the NCSCS with a database of contaminant transport and toxicological information to refine how a contaminant's degree of hazard is quantified. Arsenault's proposal suggests a desire for greater objectivity in quantifying contaminant hazard. Additional details regarding this proposal were not provided.

Table 2-1 Evaluation of classification systems for contaminated sites (Arsenault 1995)

Criteria	Classification System					
	NCSCS	HRS	HALO	ON	NB	QC
Classification factors should be based on existing information	Yes	In part	No	Yes	Yes	Yes
Environmental and human health concerns should be addressed	Yes	Yes	No	In part	In part	Yes
The system should be flexible enough to rank many different sites	Yes	No	No	Yes	Yes	No
The system should be straight forward to use	Yes	In part	In part	In part	In part	Yes
The system should be time and cost efficient	In part	No	No	Yes	Yes	In part
The system should rank sites relative to one another	Yes	Yes	In part	No	No	Yes
The system should provide for consistent interpretation of results	Yes	Yes	In part	No	No	Yes

2.1.3 Nyugen's Review

Nyugen (2004) developed a "multi-stage environmental site assessment template" to assist in risk management decisions associated with Department of National Defence sites impacted by radiological contaminants. The basis for the template is a modified form of the NCSCS suitable for radiological impacts and incorporates both human and ecological risk assessment processes. Nyugen states that although the template is designed for open radiological sites, not indoor, "it can also be used on any open site

radioactive contamination because it is also in compliance with the Canadian Environmental Assessment Act…, the Canadian Environmental Protection Act…, and the Nuclear Safety & Control Act" (2004).

Since Nyugen's work was focused on radiological contaminants, which are explicitly outside of the scope of the NCSCS (CCME 1992, 2008c), a more detailed review of his work was not conducted.

2.1.4 FCSAP Classification System

The Federal Contaminated Site Action Plan (FCSAP) Classification System is a variant of the NCSCS that was developed for Environment Canada to assess all sites included under the FCSAP. Franz (2007) provides detailed user guidance for this classification system and emphasises that it does not supersede the original NCSCS but is used to rank sites under FCSAP. The system's structure is the same as the original NCSCS; however, modifications to some evaluation factor definitions were made to provide the assessor clarity when assigning scores. An updated method of evaluation guidance was provided to improve greater objectivity in scoring. Also, this classification system emphasises the difference between known pathways & receptors and potential receptors & pathway since the assessor is required to calculate both a total known and total potential site score. This appears to be an acknowledgement that uncertainty exists in evaluating a site and this uncertainty should be made explicit when calculating an overall score for a site.

2.1.5 NCSCS Revision

Potter (2007) commented that the 1992 NCSCS was updated to the present form to address concerns expressed by users that the 1992 NCSCS was not sufficiently

objective, was difficult to use, and didn't incorporate aspects specific to contaminated site on First Nations lands or in northern Canada. Potter (2007) did not elaborate on the details of these concerns but added that several federal agencies and departments responsible for contaminated sites had developed improved versions of the 1992 NCSCS, such as the FCSAP Classification System, to resolve some of these concerns. These developments meant there was motivation to incorporate these improvements into a revised system that could be used by all federal agencies and departments.

In response, a draft of an updated NCSCS was developed, distributed for public comment, revised based on input from the public, and tested by Golder (2007) for the following aspects defined by Potter (2007):

- subjectivity of scoring between independent assessors;
- reliability of scoring for a site when using a limited amount of information versus a more detailed assessment for the same site; and,
- consistency of scoring between the proposed NCSCS, the 1992 NCSCS, and the FCSAP classification systems.

Golder (2007) used four independent assessors from within the company to evaluate these aspects using data provided by Environment Canada on a collection of 12 contaminated sites. Golder reported that Environment Canada provided contaminated site data from a range of geographical locations, for a variety of contaminant types and magnitudes, and due to different site activities (e.g., barge dock, fuel storage, landfill). To assess subjectivity of the revised NCSCS, the scores for all 12 sites as calculated by all 4 assessors were combined to calculate an average relative standard deviation (RSD) where RSD was defined as standard deviation divided by the mean. The resulting average RSD

was 17%, which Golder interpreted to be low subjectivity. The average RSD values for the 1992 NCSCS and FCSAP System were not reported meaning a clear subjectivity comparison to the revised NCSCS was not provided by Golder.

Revised NCSCS score reliability was assessed by comparing site scores given a minimal dataset and scores given an enhanced data set. Golder (2007) defines a minimal dataset as data collected during a site visit, meaning data gathered without intrusive investigation. Golder called data obtained during site assessment (e.g., Phase II ESA) an enhanced dataset. Relative percent difference (RPD) was the statistic used to complete the pair wise comparison of revised NCSCS scores for a site using minimal and enhanced datasets. RPD was calculated as $100\% \times 2 \times (x_1 - x_2)/(x_1 + x_2)$ where x_1 is the site score using the minimal or enhanced dataset and x_2 the site score using the other dataset. The result was a RPD of 21%, which was deemed by Golder to be low variability suggesting acceptable NCSCS score reliability regardless of whether a minimal or enhanced site dataset was available. Again, a comparison with the corresponding statistics for the 1992 NCSCS and FCSAP Classification System was not provided.

The consistency of revised NCSCS scores compared to 1992 NCSCS and FCSAP Classification System scores was quantified using the average bias statistic where bias was defined as $100\% \times (x_1 - x_s)/x_s$. The variable x_s is the site score calculated using the revised NCSCS and x_1 the score using either the 1992 NCSCS or FCSAP Classification System. The revised NCSCS had a negative bias of 22% and 35% compared to the 1992 NCSCS and FCSAP System, respectively. This means the revised NCSCS yields a lower site score than the 1992 NCSCS and FCSAP Classification System. Golder (2007)

concluded that “the scoring system is reliable, has reasonably low subjectivity, and is better able to distinguish between complex sites with significant contamination from those with lesser contamination and exposure pathways.” CCME subsequently issued the revised NCSCS to the public in early 2008.

2.1.6 2008 NCSCS

CCME provides detailed instructions on the 2008 NCSCS in its *Guidance Document* (2008c) and Figure 2-1 is a reprint from it that summarises the structure of the NCSCS. A user categorises a contaminated site by assigning scores to each of 65 evaluation factors that are grouped into the 16 subcategories listed in Figure 2-1. Subcategories are divided into three site characteristic categories: contaminant characteristics (5 subcategories), migration potential (6 subcategories), and receptors (5 subcategories).

For each subcategory, the user assigns a score that is either “known” or “potential”. “Known is defined as scores that are assigned based on documented scientific and/or technical observations and potential refers to scores that are assigned when something is not known, although it may be suspected” (CCME 2008c). For each subcategory, a range of scores can be assigned.

The range of allowable scores for each evaluation factor varies with larger ranges being assigned to factors that are deemed to have greater relevance to the overall hazard at a contaminated site. In cases where there is insufficient information to assign a score, the response is “do not know” and a score which is one half of the maximum allowable score is entered. This estimated score is considered an uncertain value for the evaluation factor.

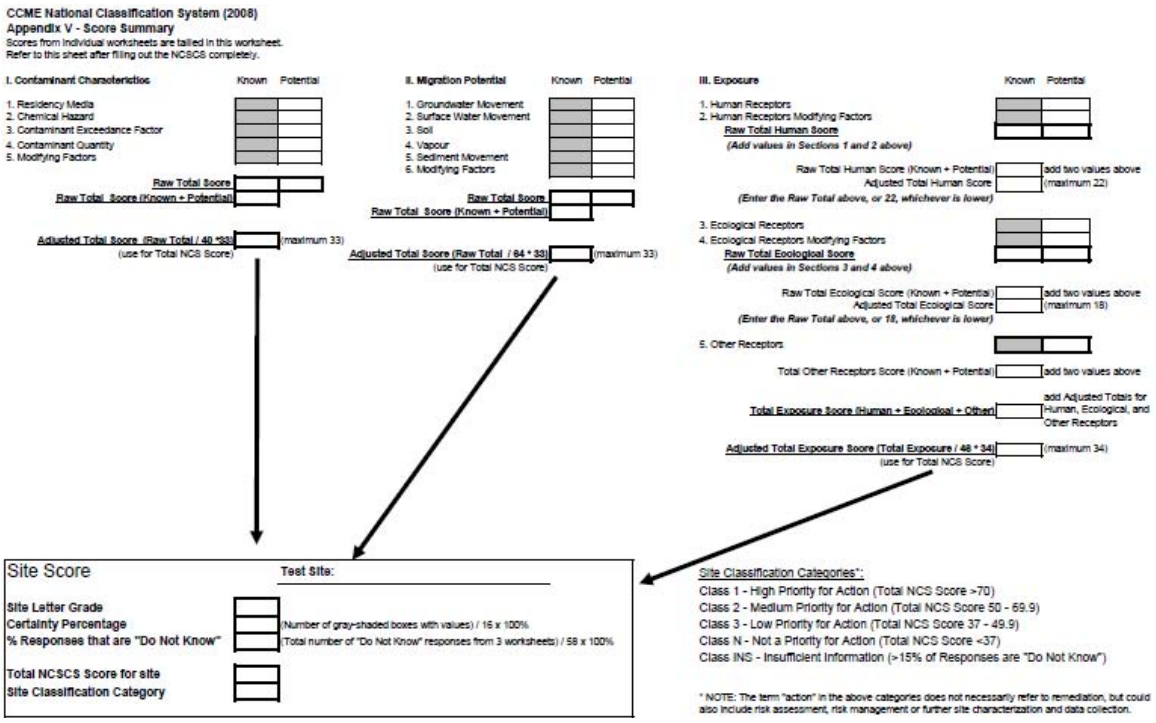

Figure 2-1 NCSCS structure reprinted with permission from CCME (2008c)[1]

Once scores have been assigned to each evaluation factor, they are combined to determine category scores ranging up to 33, 33, and 34 for Contaminant Characteristics, S_{con}; Migration Potential, S_{mig}, and Exposure, S_{exp}, respectively. These scores are added to yield an overall site score, S_{site}, ranging up to 100. The site score is then used to classify the contaminated site into one of 4 classes if sufficient information is provided (CCME 2008c):

- Class 1 – High Priority for Action, $S_{site} \geq 70$
- Class 2 – Medium Priority for Action, $50 \leq S_{site} \leq 69.9$
- Class 3 – Low Priority for Action, $37 \leq S_{site} \leq 49.9$
- Class N – Not a Priority for Action, $S_{site} < 37$

[1] Written permission to reprint from Michael Goeres, Executive Director of CCME, is documented in Appendix A.

The basis for the class cut off values is not discussed by CCME.

The NCSCS has several strengths. First, it is easy to use, intuitive, and explicitly considers contaminant characteristics, migration potential, and exposure pathways in calculating a site score, thus aligning itself with the source-path-receptor model used in environmental risk assessment. Second, score calculation uncertainty is considered by expressing the known and potential scores as a ratio where 1 indicates low or no uncertainty and zero indicates high uncertainty. Third, the use of an information uncertainty letter grade, where A indicates that the score is based on remediation reports and F indicates anecdotal information was used, is an attempt to communicate data reliability to decision makers. Fourth, the layout of the summary score sheet is concise and allows a decision maker to quickly determine what factors influence the final score and to view the uncertainty in those factors.

A potential weakness of the NCSCS is the site score is determined by adding the contaminant characteristics, migration potential, and exposure pathways scores together. Although the NCSCS is not intended as a replacement for contaminated site human health and ecological risk assessments, a reasonable expectation is for NCSCS scores to generally agree with human health and ecological risks posed by a site. If the site score can be generalised to a site risk, then addition implies site risk is a function of contaminant characteristics OR migration potential OR exposure pathways. This contradicts the generally accepted risk equation where risk depends on the presence of a source AND path AND receptor. All three factors must be present to incur a risk.

Another potential weakness is that known and potential scores within a subcategory are mutually exclusive. Referring to CCME's definition of known and

potential (2008c), a common situation that occurs when conducting an initial Phase II ESA is the data confirms the site is contaminated but there is insufficient data to identify the extent of contamination. Nonetheless, the assessor may suspect the potential magnitude of the contaminated area based on an understanding of the initial conceptual site model and the assessor's experience at other sites. A more reasonable understanding may be known and potential scores are the assumed lower and upper bounds of a range of scores based on available information.

2.2 Risk Assessment

2.2.1 Definitions

Two terms that require definition are hazard and risk. In general, risk is "a chance or possibility of danger, loss, injury, or other adverse consequences" (Barber 2004). In the context of environmental science, risk is "a measure of the likelihood or probability that damage to life, health, property, and/or the environment will occur as a result of a particular hazard" (Park 2007) where hazard is "a source of danger or disruption" (*ibid*). LaGrega et al. (2001) clarifies the distinction between risk and hazard within the field of waste management, which can be extended to contaminated site management: a hazard is a source of risk and risk is the potential exposure to the hazard. Applying basic set theory, risk is the intersection of the presence of a contaminant source (i.e. a hazard), biological receptors that can be adversely affected by the source, and contaminant exposure pathways between source and receptors. The simple Venn diagram in Figure 2-2 illustrates this hazard-pathway-receptor relationship.

Figure 2-2 Risk Venn diagram

The United States National Research Council (NRC 1983) defines human health risk assessment as characterizing the "potential adverse effects of human exposures to environmental hazards." In essence, human health risk assessment is an application of the hazard-pathway-receptor relationship where the only receptor is human. Similarly, the United States Environmental Protection Agency (USEPA 1992) defines ecological risk assessment as "the process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" where a stressor is a physical, chemical, or biological agent that can cause an adverse effect.

2.2.2 Risk Assessment Frameworks in North America

2.2.2.1 United States

Human health and ecological risk assessments frameworks in North America have been developed and refined over the past three decades. The USEPA conducted its first human health risk assessment, on vinyl chloride, in 1975 and issued its first guidance, *Interim Procedures and Guidelines for Health Risk and Economic Impact Assessments of Suspected Carcinogens*, in 1976 (USEPA 2008). In the early 1980's, the United States National Academy of Sciences (NAS) was directed by Congress to examine the risk

assessment process within the departments and agencies of the federal government. The United States Congress gave NAS this mandate because society was becoming more educated in environmental matters and Congress expected federal departments and agencies to be consistent in assessing the risk of contaminants (NRC 1983). NAS was required to investigate the benefits of maintaining objectivity in risk assessment processes by separating them from the stakeholder influenced processes of risk management; consider the feasibility of having a single organization conduct risk assessments to maximise consistency; and third, consider the feasibility of defining standards that all agencies must meet in conducting risk assessments (*ibid*).

The third objective is the most relevant of the three to the current research. NRC (1983) defined the following four components of human health risk assessment: hazard identification, exposure assessment, dose-response assessment, and risk characterization. NRC described hazard identification as the process of determining whether a chemical is linked to an adverse health effect; exposure assessment as estimating the degree to which a human is exposed to a chemical; dose-response assessment as assessing the relationship between exposure duration and magnitude to the likelihood of adverse health effects; and risk characterization as describing the human health risk type and magnitude including a discussion of uncertainty.

Building upon the principles established in the 1983 NRC document, the USEPA published its *Framework for Ecological Risk Assessment* (USEPA 1992) to establish the process of investigating risks to non-human receptors at the individual, population, community, or ecosystem levels. The USEPA redefined the first risk assessment component as problem formulation, which is the process of identifying physical or

chemical stressor characteristics (e.g. related to a brine release), ecosystems potentially at risk, ecological effects, endpoint selections, and the conceptual site model (USEPA 1992). In problem formulation, identifying the ecosystem components potentially at risk (e.g. a plant community) is necessary to determine populations or communities that may be adversely affected by the stressors. Ecological adverse effects are the result of the action of stressors on ecological receptors (e.g. stressed vegetation). Endpoint selection is the process of choosing measurable variables that quantify changes to ecological receptors (e.g. quantifiable reduction in plant community biodiversity) due to a stressor. The USEPA (1992) describes conceptual site model development as:

> "…a preliminary analysis of the ecosystem, stressor characteristics, and ecological effects…to define possible exposure scenarios…For chemical stressors, the exposure scenario usually involves consideration of sources, environmental transport, partitioning of the chemical among various environmental media, chemical/biological transformation or speciation processes, and identification of potential routes of exposure (e.g., ingestion)."

Further discussion regarding conceptual model development is provided later in this chapter. In the *Framework for Ecological Risk Assessment*, exposure characterization and ecological effects characterization, the second and third risk assessment components, are combined under an analysis phase that follows problem formulation (USEPA 1992). The final risk assessment component, risk characterization, is described in similar terms as the NRC (1983) albeit for ecological receptors.

Subsequent to the 1992 USEPA report, the NRC Committee on Risk Assessment Methodology published *A Paradigm for Ecological Risk Assessment* (NRC 1993) to augment the human health risk assessment process defined by NRC in 1983 by

incorporating the specifics of ecological risk assessments. The NRC (1993) endorsed a similar four component risk assessment process: hazard identification, exposure assessment, exposure-response assessment, and risk characterization.

2.2.2.2 Canada

In Canada, the Canadian Council of Ministers of the Environment (CCME) defined the structure of ecological risk assessments in *A Framework for Ecological Risk Assessment: General Guidance and Technical Appendices* (CCME 1996 & 1997). These documents reference standards by NRC (1983) and the USEPA (1992). Like the NRC and USEPA, CCME (1997) adopted a four component risk assessment structure: receptor characterization, exposure assessment, hazard assessment, and risk characterization.

Health Canada established the structure of human health risk assessments related to contaminated sites under the purview of the federal government in *Federal Contaminated Site Risk Assessment in Canada, Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA)* and *Part III: Guidance on Peer Review of Human Health Risk Assessments for Federal Contaminated Sites in Canada* (HC 2004a,c). It named the four components as problem formulation, exposure assessment, hazard assessment, and risk characterization.

2.2.3 Discussion

Specific to the current research, the USEPA, NRC, CCME, and Health Canada identify risk assessment in terms of four related components. Although the first step is called hazard identification by the NRC (1983), receptor characterization by CCME (1996 & 1997), and problem formulation by the USEPA (1992) and Health Canada (2004a,c), the common intent is to define the conceptual site model (CSM) for a site,

which means contaminant sources, exposure pathways, and critical receptors are understood. For the purposes of the current research, this risk assessment component is termed problem formulation. All four sources describe the second component as exposure assessment or characterization. CCME (1996 & 1997) and Health Canada (2004a,c) provide details regarding the expectations in conducting exposure assessment and these documents form the basis of exposure assessment in the current research. The third risk assessment component, conducted in parallel with exposure assessment, is termed dose-response assessment, ecological effects characterization, and exposure-response assessment by the NRC (1983), USEPA (1992), and NRC (1993), respectively, and hazard assessment by both CCME (1996 & 1997) and Health Canada (2004a,c). The common intent is to understand contaminant toxicity to the receptors identified in the problem formulation component. Since an understanding of contaminant toxicity is the objective, this risk assessment component is called toxicity assessment in the current research. All four documents describe the fourth component as risk characterization. The CCME (1996 & 1997) requirements for risk characterization were used as a guide in the current research.

2.2.4 Combining Risk Assessment Results

A contaminated site's NCSCS score is an indicator of risks to both human and ecological receptors combined. Ideally, any risk assessment protocol used for comparison should also combine results into a single measure or at least combine ecological risk assessment results into a single measure that can be presented alongside human health risk assessment results. Suter *et al.* (1995) recognised that developing a common risk scale is a challenge because of the varied assessment endpoints among receptors but

stated "…the apples of health risk must be balanced against the oranges, pineapples, and plums of ecological risk". As a possible solution, Suter *et al.* proposed human health and ecological risks be classified based on environmental consequences and suggested three categories: *de minimis*, intermediate, and *de manifestis*. Classification in this way allows an assessor to make qualitative environmental consequence comparisons across receptors (*ibid*).

In 2003, Suter *et al*. presented a *Framework for the Integration of Health and Ecological Risk Assessment*, which was a collaborative effort of the World Health Organization's (WHO) International Programme on Chemical Safety (IPCS), the Organization for Economic Cooperation and Development (OECD), and the USEPA. This framework document suggested:

> "An integrated assessment would use some common presentation of results (e.g., proportions of human and otters in a region experiencing reproductive impairment) as well as any species-specific endpoints, and would explain differences in the magnitude of effects. Similarly, the uncertainties would be presented in a common form (e.g., cumulative probability). This integrated risk characterization would greatly facilitate the task of communicating risks to risk managers and the public".

This is a restatement of the need for a single risk measure and is also reiterated by Bridges (2003), Suter (2004), Vermeire *et al.* (2007). However, pragmatic and quantitative solutions that can be easily implemented are not provided. There doesn't appear to be a generally accepted method of combining human health and/or ecological risk assessment results into a single quantitative measure.

Chapter Three: Methods

3.1 Contaminated Sites

3.1.1 Site Selection

Contaminated sites under the jurisdiction of federal departments or agencies were chosen because the NCSCS or a variant was used to classify these sites. The Federal Contaminated Site Inventory (FCSI) is a database containing information on over 19,000 contaminated sites that are the responsibility of the Government of Canada (TBCS 2005). Amongst these sites, approximately 8,000 of them have been classified as high, medium, low, or not a priority for action using the NCSCS. The FCSI was used to search for and select candidate sites based on four criteria:

- the sites should represent the more frequently encountered contaminant types;
- the sites should represent the varied climate and geography across Canada;
- at minimum, a Phase II ESA must have been completed at each site; and,
- the sites should represent NCSCS Classes 1, 2, 3, and N.

Figure 3-1 shows the proportions of sites impacted by various contaminant types. Almost 90% of contaminated sites have soil impacted by metals; petroleum hydrocarbons (PHCs) including benzene, toluene, ethylbenzene, xylenes (BTEX); or polycyclic aromatic hydrocarbons (PAHs). Thus, the selected sites focused on these contaminants.

Sites were chosen from the Northwest Territories, Nunavut, and Yukon to represent Canada's North; sites in British Columbia and the Alberta Foothills to represent the West Coast and Rocky Mountains; sites in Saskatchewan and Manitoba for the Prairies; sites in Ontario for Central Canada; and sites in the Atlantic Provinces for the Canadian Maritimes. To meet the third criterion, sites were selected from a list of those

that met *Step 6 – Detailed Testing Program* of the Federal 10 Step Process (CSMWG 1999). To meet the fourth criterion, each of the four NCSCS classes was represented by approximately an equal number of sites by using the class assignments listed in the FCSI as a guide.

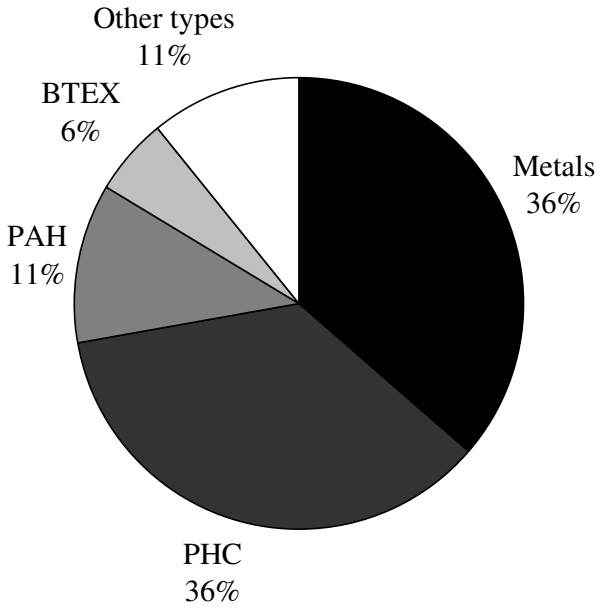

Figure 3-1 Occurrence of contaminant types in FCSI (TBCS 2005)

3.1.2 Data Gathering

Twenty sites, a manageable number for this research, were selected from the FCSI and environmental site assessment (ESA) information was requested via the federal *Access to Information Act* (GoC 1985). A formal information request form with application fee was sent to each federal government institution listed in the FCSI as the reporting organization. For each site the request was for:

> "Paper or pdf copies of environmental site assessment or management documents related to the follow Site registered in the Federal Contaminated Site Inventory (FCSI): [insert Site Name]. Examples of requested documents related to the Site may include reports on the following topics: Phase I Environmental Site Assessments

> (ESA), Phase II ESA, groundwater monitoring, human health or ecological risk assessment, risk management plan, remedial action plan, conceptual site model, NCS classification. This information is requested to support Master of Science research in the area of contaminated site assessment."

The contacted federal government institutions responded by providing the requested information in a combination of paper and electronic formats within a range of 30 day to 180 days of requests being submitted and 90 days, on average. Related correspondence from federal institutions is located in Appendix A.

3.2 Risk Assessment Protocol

The second research objective is to evaluate the performance of the NCSCS against a rigorous risk assessment protocol. Since the NCSCS is a screening tool intended to classify contaminated sites using readily available site information, a reasonable assumption is to evaluate it by applying preliminary or screening level risk assessments using similar input data. Health Canada describes a preliminary quantitative risk assessment (PQRA), in the context of human receptors, as a screening assessment that uses "prescribed methods and assumptions that ensure that exposures and risks are not underestimated" (2004a). CCME describes a screening ecological risk assessment as a tier 1 risk assessment "based primarily on data from literature, previous or preliminary studies of the contaminated site, monitoring studies, historical data of the site, and a reconnaissance visit to evaluate the receptors, exposure, hazards, and risk at the site" (1996). For the purposes of this study, both screening human health and ecological risk assessments are referred to as a PQRA. Both Health Canada (2004a) and CCME (1996, 1997) identify the major elements of a PQRA as: problem formulation (also known as a

conceptual site model), exposure assessment, hazard (or toxicity) assessment, and risk characterization. This structure was adopted in providing an overview of the PQRAs applied in this research.

3.2.1 Problem Formulation

Problem formulation includes: screening and identifying contaminants of potential concern (COPCs); identification and description of potential receptors; and identification of operable exposure pathways (HC 2004a). In essence, problem formulation is a description of the conceptual site model (CSM) for a contaminated site. CCME (2006) was used as a primary source in establishing the CSM framework for the PQRAs. It was chosen for this research because it is a national standard based on consensus among the participating provincial and territorial environmental protection agencies.

3.2.1.1 Contaminants of Potential Concern

The current NCSCS considers both organic and inorganic COPCs but excludes those that are radiological, biological, or explosive (CCME 2008c). Therefore, the PQRAs were limited to assessing risk of COPC that were not radiological, biological, or explosive to match the scope of the NCSCS.

3.2.1.2 Receptors

Biological receptors identified by CCME (2006) were used in the PQRAs. The relevant human receptors are the toddler, aged 7 months to 4 years old, for threshold effect contaminants and an adult, a person 18 years old or greater, for non-threshold effect contaminants (e.g. carcinogens) (HC 2004a). In addition, First Nations toddlers and adults were considered sensitive human receptors because Health Canada (2004a) has

concluded that in general they have greater dependence on local fish and game compared to the overall Canadian population.

Guidelines published by Alberta Environment (AENV 2009a,b) are based on CCME (2006) guidance and have identified the following ecological receptors groups:

- terrestrial plants and soil invertebrates;
- soil microorganisms responsible for nutrient and energy cycling;
- agricultural livestock;
- wildlife including primary, secondary, and tertiary consumers; and,
- aquatic life.

Consistent with CCME (2006, 2008a,b) and AENV (2009a), a dairy cow was used as the surrogate ecological receptor for livestock because toxicity data is readily available and because of the cow's "economic importance" (AENV 2009a). Similarly, CCME and AENV consider the meadow vole (*Microtus pennsylvanicus*) to be the surrogate, primary consumer, mammal species in developing soil remediation guidelines because of its high soil ingestion rate relative to its low body weight. Given its widespread distribution across Canada (Bernhardt 2009), the meadow vole was used as a surrogate species in the PQRAs.

Based on CCME (2006) guidance, the following food chain was applied when assessing the effect of bioaccumulating contaminants: soil → earthworm → secondary consumer → tertiary consumer. Earthworms have a high soil ingestion rate relative to body weight and are assumed to retain high residual contaminant concentrations in their tissue. This concentration is then directly available to secondary consumers. Consistent with CCME (2008b), the masked shrew (*Sorex cinereus*) was the surrogate secondary

consumer chosen for the PQRAs because it is an insectivore that preys on earthworms and has a widespread distribution across Canada (Bernhardt 2009). The American kestrel (*Falco sparverius*) was the chosen surrogate, tertiary consumer used in the PQRAs because it includes small mammals, such as shrews, in its diet (USEPA 1993) and because this species has wide spread distribution through Canada (Bernhardt 2009). This species is referenced in soil quality guidelines published by federal (EC 2001) and provincial environmental agencies (OMOE 2008).

3.2.1.3 Coordinate System and Soil Strata

A polar coordinate system was used to spatially reference contaminated site data in ESA reports and was selected to simplify contaminant transport calculations. The origin was positioned within the contaminant source zone where the majority of detected contaminants were at their maximums. A site was then divided into cells, $i_{\theta,r}$, each identified by its direction, θ, and radius from the origin, r. The 8 cardinal and ordinal directions (e.g., N, NE, E,…) were referenced for simplicity. Radii in metres were selected based on the following quasi-logarithmic series: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600, 700, 800, 900, & 1,000. At each cell, soil was divided vertically into three strata where topsoil was defined as the top 0.3 m, surface soil as between 0.3 metres and 1.5 metres below ground surface (mbgs), and subsoil below 1.5 mbgs. The surface soil and subsoil depth definition are consistent with definitions proposed by CCME (2006). The demarcation between unsaturated and saturated soil was site specific depending on measured or assumed shallow groundwater depth. Where a cell corresponded to a water course or water body, soil strata were not defined and the cell was called “water”.

In each cell, soil strata were characterised as coarse grained or fine grained using the definition and default soil properties provided by CCME (2006). Similarly, CCME default values were applied for unsaturated and saturated soil. Saturated soil was also divided into frozen or not frozen to account for permafrost regions.

Topsoil was classified as being either impervious, such as asphalt or concrete; bare soil, meaning no vegetation; partially vegetated, meaning approximately half of the soil surface covered by plant growth; and fully vegetated. Along with soil texture, these topsoil characteristics were important in estimating precipitation infiltration rates and wind generated, air borne particulate concentrations.

At each cell, each measured contaminant concentration in soil was assigned to one of the three defined soil layers: topsoil, surface soil, and subsoil. If more than one result was available per cell layer, the maximum result was used. Groundwater results were assigned to the saturated zone and the most recent result used.

The schematic in Figure 3-2 illustrates the coordinate system's cells and how the cell grid was overlaid upon a contaminated site. The grey ellipse represents a contaminant source zone with a plume and the black dots represent sample locations within the cells.

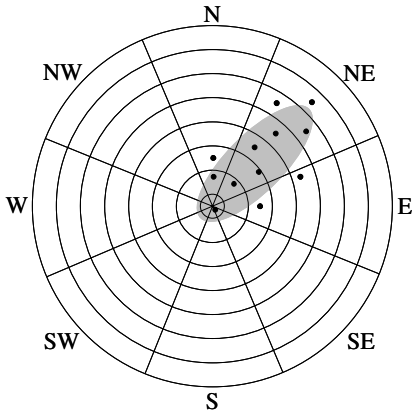

Figure 3-2 Polar coordinate system

3.2.1.4 Land Uses

Each cell was assigned one of seven land uses to determine the relevant receptors and exposure parameters. The following land uses as defined by CCME (2006) were used in the PQRAs: agricultural, residential, parkland, commercial, and industrial. In addition to the CCME land uses, a natural area land use as defined by AENV (2009a) was used in the PQRAs to accommodate contaminated sites located in remote areas not expected to be occupied by humans and thus not suitably classified under the other defined land uses. Finally, areas capable of sustaining an aquatic ecosystem, meaning fish, aquatic plants, and invertebrates, were defined as "water". Table 3-1 summarises the seven land uses and corresponding receptors. The selection of land use(s) for a site was based on information in the associated environmental site assessment (ESA) reports, aerial imagery, and land use zoning maps, where available.

Table 3-1 Land use receptors

Receptor	Land Use						
	Nat	**Agri**	**Resi**	**Park**	**Com**	**Ind**	**Wat**
Human toddler	-	Yes	Yes	Yes	Yes	-	-
Human adult	-	Yes	Yes	Yes	Yes	Yes	-
Terrestrial plant & soil invertebrates	Yes	Yes	Yes	Yes	Yes	Yes	-
Soil microorganisms	Yes	Yes	Yes	Yes	Yes	Yes	-
Cow	-	Yes	-	-	-	-	-
Meadow vole	Yes	Yes	Yes	Yes	-	-	-
Masked shrew	Yes	Yes	Yes	Yes	-	-	-
American kestrel	Yes	Yes	Yes	Yes	-	-	-
Aquatic Life	-	-	-	-	-	-	Yes

3.2.1.5 Additional Cell Attributes

Additional cell attributes were the presence or absence of habitable buildings, types of groundwater usage, and the presence or absence of sensitive human receptors.

The presence of buildings intended for human occupancy located on contaminated soil or groundwater creates potential for indoor air quality issues for occupants due to contaminant vapours infiltrating the building. Contaminated groundwater used for potable water, livestock watering, or crop irrigation increases risk to human and livestock receptors as well as irrigated crop production.

3.2.1.6 Meteorological Data

Data on annual precipitation and the number of days with a temperature below zero Celsius were necessary to estimate water infiltration rate via the vadose zone and the biodegradation rate of contaminants in the vadose zone, respectively. Environment Canada (2010) meteorological data was obtained from a weather station in the vicinity of each contaminated site.

3.2.2 Exposure Assessment

Health Canada (2004a) states that exposure assessment includes:

> "…all exposure equations, chemical-specific characteristics, any necessary assumptions, the concentration (maximum, arithmetic average) used to represent the concentrations of COPCs in applicable media (air, water, soil, vegetation, etc.), and identification of and the results from the application of any methods or models required to estimate concentrations in one environmental medium based on those in another medium. Models may include those that employ measured soil-borne concentrations to estimate concentrations in groundwater, in surface water, in indoor air (volatile contaminants only), in ambient air, in agricultural produce, in vegetation used as country foods, in wildlife or fish that serve as food, etc."

3.2.2.1 Chemical Properties

Information on the following chemical properties was needed to predict how contaminants behaved and were transported through and across media: organic carbon

partitioning coefficient, K_{oc}; distribution coefficient, K_d; dimensionless Henry's constant, H'; molecular diffusion coefficients in air, D_a, and water, D_w; aqueous solubility, S; vapour pressure, p_v; and molecular weight, M_w. In addition, information on the following chemical parameters were needed: half life in vadose and saturated zones, $t_{1/2us}$ and $t_{1/2s}$; absorption factors for human gastrointestinal tract, AF_G; lungs, AF_L; and skin, AF_S; and biotransfer factors to beef, B_b; milk, B_m; plants and produce, k_1 to k_3; and earthworms & small mammals, k_4 to k_6;. Data was obtained from the following sources: AENV (2009a), Baes *et al.* (1984), BCMELP (1996), CCME (2008a,b, 2009), Gustafson *et al.* (1997), Health Canada (2004a), Mackay *et al.* (2006), ORNL (2009), Travis & Arms (1988), and USEPA (1996, 2005, 2009a,b). Given the large volume of data gathered, values used in the PQRAs are summarised in Table B–1 to Table B–4 under Appendix B.

3.2.2.2 Exposure Routes and Durations

Table 3-2 summarises the exposure route for each of the previously identified receptors and is based on information provided by CCME (2006) and AENV (2009a). Exposure durations, physiological parameters, and media or food specific exposure parameters for human receptors were obtained from Health Canada (2004a) and CCME (2006). Ecological receptor exposure assumptions in Table 3-3 are based on guidance provided by CCME (2006) and AENV (2009a) with input from USEPA (1997).

Table 3-2 Exposure routes

Receptor	Contaminated Medium	Exposure Route		
		Ingestion	Inhalation	Contact
Human	Topsoil	Yes	-	Yes
	Surface soil	Yes	-	Yes
	Groundwater	Yes	-	-
	Particulate	-	Yes	-
	Indoor air	-	Yes	-
	Beef	Yes	-	-
	Milk	Yes	-	-
	Produce	Yes	-	-
Plants & invertebrates	Topsoil	-	-	Yes
	Surface soil	-	-	Yes
	Irrigation water	-	-	Yes
Soil microorganisms	Topsoil	-	-	Yes
	Surface soil	-	-	Yes
Cow	Topsoil	Yes	-	-
	Water	Yes	-	-
	Plants	Yes	-	-
Meadow vole	Topsoil	Yes	-	-
	Surface soil	Yes	-	-
	Plants	Yes	-	-
Masked shrew	Topsoil	Yes	-	-
	Surface soil	Yes	-	-
	Earthworm	Yes	-	-
American kestrel	Topsoil	Yes	-	-
	Masked shrew	Yes	-	-
Aquatic Life	Surface water	-	-	Yes
	Sediment	-	-	Yes

Table 3-3 Ecological receptor exposure parameters

Parameter	Unit	Receptor			
		Cow	Meadow Vole	American Kestrel	Masked Shrew
Body weight, *BW*	kg	550	0.017	0.124	4.5×10^{-3}
Air inhalation rate, IR_a	m^3/d	85.0	0.0623	0.0820	7.24×10^{-3}
Water ingestion rate, *WIR*	kg/d	100	3.57×10^{-3}	0.0146	7.65×10^{-4}
Soil ingestion rate, *SIR*	kg/d	0.747	5.79×10^{-5}	-	1.94×10^{-5}
Food ingestion rate, *FIR*	kg_{dw}/d	8.60	2.41×10^{-3}	0.011	8.09×10^{-4}

3.2.2.3 Dose Equations

Human exposure equations provided by Health Canada (2004a) were used in calculating predicted daily intake (*PDI*) values, with units $mg \cdot kg_{bw}^{-1} \cdot d^{-1}$, at each cell via soil ingestion, particulate inhalation, vapour inhalation, water ingestion, soil contact with skin, and contaminated food ingestion. Figure 3-3 summarises the input data required to calculate doses.

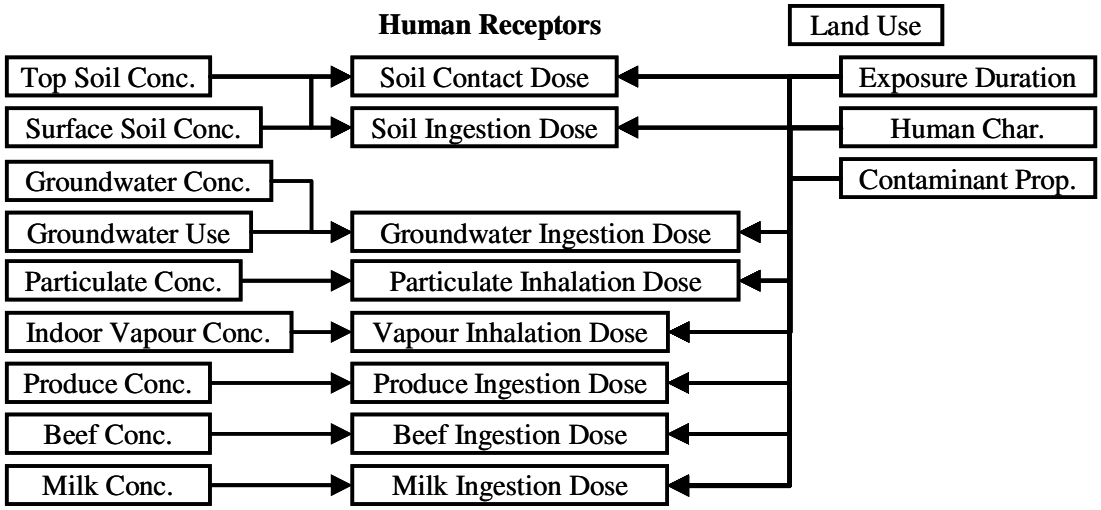

Figure 3-3 Influence diagram for human receptor dose calculations

The soil contact doses, having units of mg/kg, for plants & soil invertebrates and soil microorganisms were determined from the maximum of measured topsoil and surface soil concentrations. An irrigation water contact dose was also calculated for plants, specifically crops and produce, where an agricultural land use was present (CCME 2006). The contaminant concentration in irrigation water was assumed to be the same as in groundwater within the same cell. Figure 3-4 summarises the input data required to calculate doses.

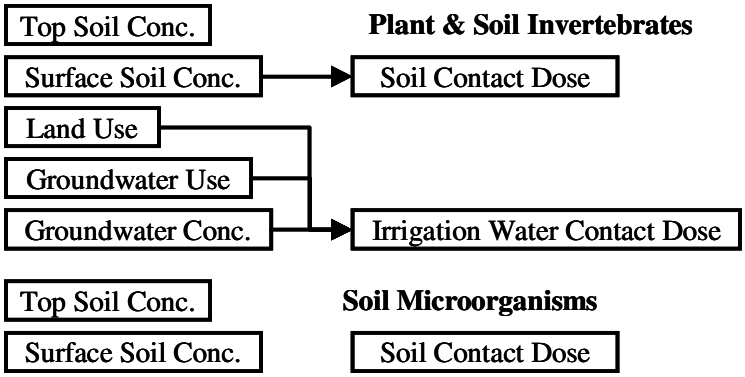

Figure 3-4 Influence diagrams for plant & invertebrate and soil microorganism dose calculations

Primary consumer *PDI* equations for contaminated soil, water, and plant food exposure were used to calculate doses for the cow and meadow vole (CCME 2006):

Equation 3-1 $$PDI_{Ing} = C \times IR \times BF / BW$$

where:

- PDI_{Ing} = predicted daily intake via soil ingestion, water ingestion, or food ingestion ($mg \cdot kg_{bw}^{-1} \cdot d^{-1}$);
- C = measured maximum contaminant concentration in soil, water, or food (mg/kg);
- IR = receptor specific soil, water, or food ingestion rate (kg/d);
- BF = contaminant bioavailability factor, conservatively set to 1; and,
- BW = receptor body weight (kg).

In Equation 3-1, the contaminant concentration in topsoil was used for the cow and the maximum of topsoil and surface soil concentrations for the meadow vole. Refer to Figure 3-5 for the respective dose calculation influence diagrams.

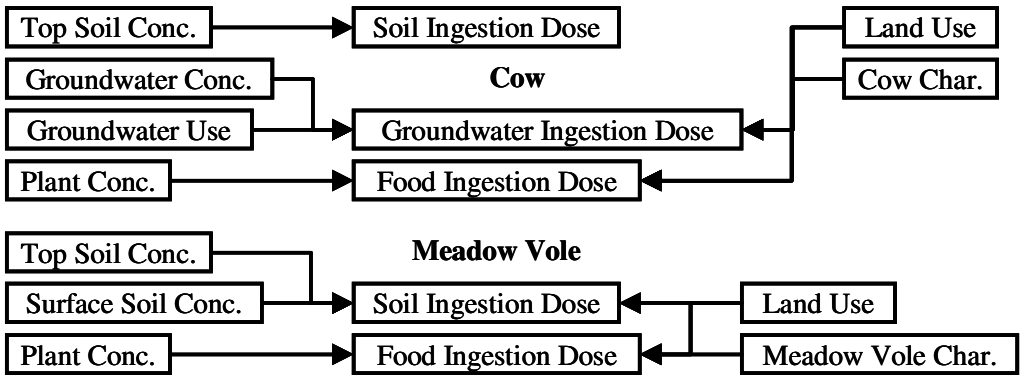

Figure 3-5 Influence diagram for cow and meadow vole dose calculations

Secondary and tertiary consumer equations *PDI* equations for contaminated soil and food exposure were used to calculate doses for the masked shrew and American kestrel, respectively (CCME 2006). The contaminated food sources for the shrew and kestrel were the earthworm and masked shrew, respectively.

Equation 3-2 $$PDI = C \times IR \times BF \times AF_{fr} \times AF_{e} / BW$$

Variables are as defined previously with the addition of the proportion of a consumer's foraging range within contaminated site, AF_{fr}, and proportion of time that a consumer spends on the contaminated site, AF_e. Both variables were conservatively set to unity in the PQRAs. In Equation 3-2, the contaminant concentration in topsoil was used for the American kestrel and the maximum of topsoil and surface soil concentrations for the masked shrew. Refer to Figure 3-6 for the respective dose calculation influence diagrams.

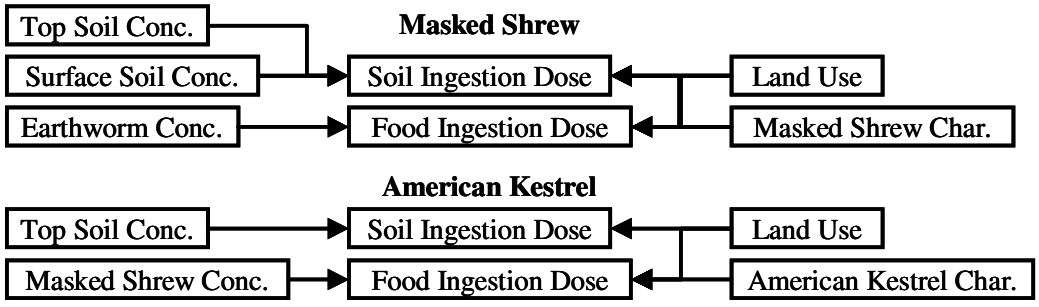

Figure 3-6 Influence diagram for masked shrew and American kestrel dose calcs.

Water and sediment contact doses, having units of mg/L and mg/kg, respectively, for aquatic life were the measured concentrations in water and sediment, respectively.

3.2.2.4 Biotransfer Equations

Contaminant concentrations in plants, produce, earthworms, masked shrew, beef, and milk (i.e., receptor food sources) were calculated using equations from or based on CCME (2006). For plants and produce, contaminant concentrations were estimated using Equation 3-3, which was derived to accommodate bioaccumulation data expressed in the source documents as either a biotransfer factor, B_p, or as a regression equation expressed in the form $\ln(C_p) = k_2 \ln(C_s) + k_3$:

Equation 3-3 $$C_p = k_1 \exp[k_2 \ln(C_s) + k_3]$$

where:

- C_p = contaminant concentration in dry produce or plants (mg/kg_{dw});
- C_s = contaminant concentration in soil (mg/kg); and,
- k_1, k_2, and k_3 = contaminant specific bioaccumulation constants.

In cases where bioaccumulation data was not available for a contaminant, k_1 was set to zero meaning the contaminant was assumed not to bioaccumulate. The maximum contaminant concentration in topsoil and surface soil was used in the calculation.

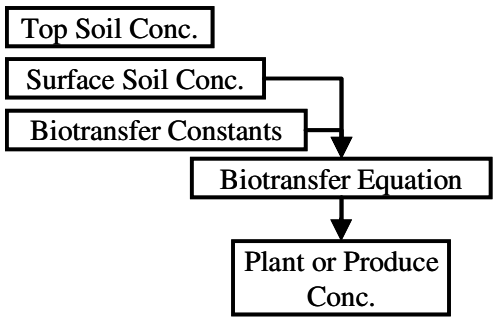

Figure 3-7 Influence diagram for calculated plant and produce concentrations

Similarly, biotransfer factors were also required to estimate the concentrations of contaminants in food consumed by masked shrew and American kestrel. The equation below was used to estimate contaminant concentrations in the assumed primary food source for these two consumers: earthworms and masked shrew, respectively:

Equation 3-4 $$C_{worm} \; or \; C_{shrew} = k_4 \exp[k_5 \ln(C_s) + k_6]$$

where:

- C_{worm}, C_{shrew} = contaminant concentration in earthworms and masked shrew (mg/kg_{dw}); and,
- k_4, k_5, k_6 = contaminant specific bioaccumulation constants.

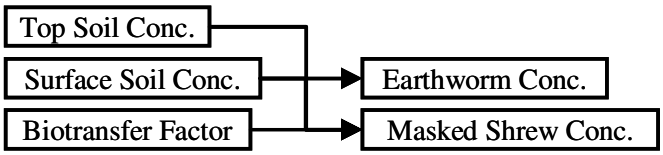

Figure 3-8 Influence diagram for calculated earthworm and masked shrew concentrations

Potential contaminant concentrations in beef and milk were calculated using the equations below recommended by CCME (2006):

Equation 3-5 $$C_b = B_b \times C_s \times IR_s$$

Equation 3-6 $$C_m = B_m \times C_s \times IR_s$$

where:

- C_b, C_m = contaminant concentration in beef and milk, respectively (mg/kg); and,
- B_b, B_m = biotransfer factor for beef and milk, respectively (d/kg).

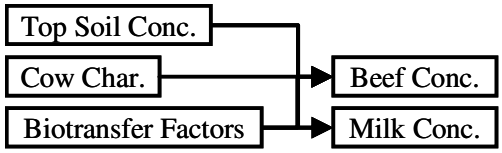

Figure 3-9 Influence diagram for calculated beef and milk concentrations

3.2.2.5 Contaminant Transport Equations

The contaminant transport models and assumptions recommended by CCME (2006) were used as a basis in predicting the transport of contaminants via groundwater, vapour, wind, and surface water runoff. These models are simplifications of actual transport process but are appropriate given the limited information typically available for most contaminated sites.

3.2.2.5.1 Vapour Transport

At each cell, the estimated soil vapour concentrations in impacted surface soil and in subsoil, $C_{a,soil}$, were calculated using the following partitioning equation (CCME 2006):

Equation 3-7 $$C_{a,soil} = C_t H' \rho_b / (\theta_w + K_d \rho_b + H' \theta_a)$$

where:

- C_t = total concentration of contaminant in soil (mg/kg);
- ρ_b = soil bulk density in vadose zone (g/cm^3);
- θ_a = air filled porosity (-); and,
- θ_w = water filled porosity (-).

The vapour concentration immediately above impacted groundwater, $C_{a,gw}$, was calculated using $C_{a,gw} = C_w H'$. The ideal gas law equation was used to determine the

maximum vapour concentration from impacted soil or groundwater. A temperature of 294 K was used based on measured soil temperatures beneath buildings (CCME 2008a).

At each cell, the maximum of vapour concentrations in impacted surface soil and subsoil and above impacted groundwater, C_a, was compared to $C_{a,max}$, the contaminant's vapour pressure. If C_a exceeded $C_{a,max}$, then C_a was set equal to $C_{a,max}$. The resultant C_a value was used in subsequent vapour transport calculations.

If a cell had a vapour concentration greater than zero and at least one habitable building was present, a soil vapour attenuation factor, α_{vap}, was determined to predict the indoor vapour concentration, $C_{a,indoor}$. If the distance between the contaminant source and the building foundation was less than 0.30 m, α_{vap} was set to 0.01 as per guidance from AENV (2009b). Otherwise, the Johnson & Ettinger (1991) equation as presented by AENV (2009b) was used to calculate α_{vap}. The indoor vapour concentration was estimated by multiplying the vapour concentration by the vapour attenuation factor: $C_{a,indoor} = C_a \alpha_{vap}$. Additional attenuation due to contaminant vapour mixing with indoor air was not considered. Figure 3-10 summarises the inputs needed to calculate indoor vapour concentrations.

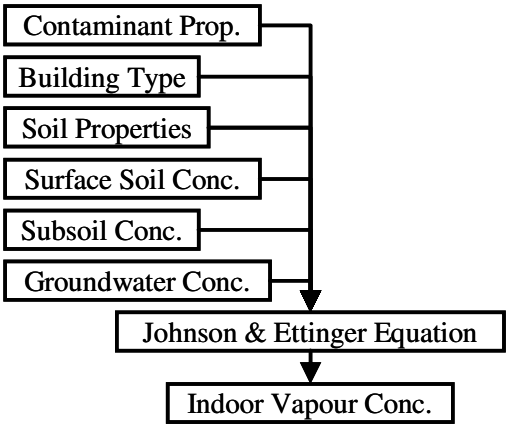

Figure 3-10 Influence diagram for calculated indoor vapour concentrations

3.2.2.5.2 Particulate Transport

Health Canada (2004a) recommends using an estimated annual average particulate concentration of 0.76 mg/m^3 above a contaminated site when conducting risk assessments. The basis of this value is the following "unlimited reservoir" Equation 3-8 developed by Cowherd *et al*. (1985) as presented by the USEPA (1996, 2002) using default input parameters used by the USEPA (*ibid*):

Equation 3-8 $$C_{pm} = 10^{-5}\left(C_{wind}/Q_{pm}\right)(1-V)\left(U_m/U_t\right)^3 F(x)$$

where:

- C_{pm} = average particulate concentration in ambient air (kg/m^3);
- C_{wind}/Q_{pm} = normalised annual average particulate concentration (0.01101 kg/m^3 per g/m^2·s);
- V = fraction of surface covered by vegetation (0.5);
- U_m = mean annual wind speed (4.69 m/s);
- U_t = equivalent erosion threshold wind speed at 7 m above surface (11.32 m/s); and,

- $F(x)$ = function dependent on U_m / U_t (0.194).

The default vegetation cover fraction, *V*, of 0.5 implies that on a per square metre basis half of the contaminated site surface is covered by vegetation that restricts wind scour and particulate matter entrainment. For the PQRAs, *V* was considered a variable and assigned a value of zero for a completely vegetated site or site with a non-erodible surface (e.g. asphalt), 0.5 for a partially vegetated site, and 1.0 for a site dominated by bare soil.

At each cell, the particulate contaminant concentration, C_{part}, was calculated using the equation $C_{part} = C_{ts} \times C_{pm}$ where C_{ts} is the contaminant concentration in topsoil (mg/kg).

3.2.2.5.3 Groundwater Transport

CCME (2006) considers four processes in the transport of soil contaminants to groundwater: soil leachate generation, vadose zone transport, groundwater mixing, and groundwater transport. At each cell and soil stratum, soil leachate concentration, C_l, was estimated using the following logic: If the measured contaminant concentration in soil, C_s, was less than the soil concentration in equilibrium with the contaminant's effective solubility, $C_{s,max}$, then $C_l = C_s / K_d$; otherwise the leachate concentration was set to the effective solubility, S_e, where $S_e = XS$, $C_{s,\max} = S_e K_d$, and:

- K_d = distribution coefficient (mL/g);
- S = pure phase solubility of contaminant (mg/L); and,
- X = mole fraction of contaminant in a mixture, conservatively set to unity.

The maximum calculated leachate concentration in topsoil, surface soil, and subsoil was then used in subsequent calculations.

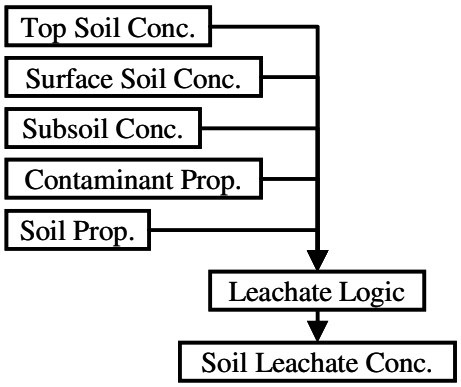

Figure 3-11 Influence diagram for calculated soil leachate concentration

Vadose zone contaminant transport is influenced by precipitation infiltration rates. AENV (2009a) concludes that groundwater recharge by infiltration is less than 10% of precipitation through coarse grained soils and less than 2% through fine grained soils based on a significant amount of research conducted by others for the Prairies provinces. These percentages were also used in this research at contaminated sites outside of the Prairies.

At each cell, if the soil surface had an impermeable cover, such as asphalt, the assumed precipitation infiltration rate, *I*, was zero. However, if the surface was permeable and the vadose zone soil was coarse grained, as defined by CCME (2006), infiltration rate was calculated as 10% of the average annual precipitation for the contaminated site. The average annual precipitation was based on historical climate normals published by Environment Canada (2010). If the vadose zone was fine grained, the infiltration rate was calculated as 2% of average annual precipitation.

The attenuation coefficient, α_{us}, for a contaminant as it migrates through the vadose zone was calculated using the series of equations based on CCME (2006) and published by AENV (2009b). The attenuated leachate concentration before mixing with unimpacted groundwater, $C_{l,gw,i}$, was calculated using $C_{l,gw,i} = C_l \times \alpha_{us}$. The area weighted average, as calculated using Equation 3-9, of all $C_{l,gw,i}$ values beneath a contaminant source zone was used for the subsequent groundwater transport calculations.

Equation 3-9

$$C_{l,gw,ave} = \sum_{i=0}^{n} w_i C_{l,gw,i} \Big/ \sum_{i=0}^{n} w_i$$

where:

- w_i = distance interval between a cell's upper and lower bound along a given direction (m); and,
- $C_{l,gw,i}$ = leachate concentration in groundwater within a cell before mixing with unimpacted groundwater (mg/L).

For simplicity, the groundwater mixing factor was conservatively set to unity.

As leachate percolates through the vadose zone, contaminant can partition onto the surface of soil particles according to the following equation: $C_s = C_{l,gw,ave} \times K_d$. At each cell for each soil stratum, if the predicted contaminant concentration adsorbed to soil was greater than the measured value, the concentration was updated with the predicted value.

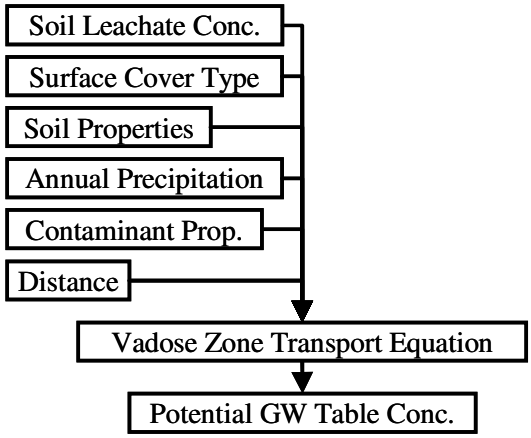

Figure 3-12 Influence diagram for potential concentration at groundwater table

The two dimensional, steady state form of the groundwater contaminant transport equation published by AENV (2009b), which is based on CCME (2006), was used in estimating a groundwater contaminant attenuation factor, α_{gw}, down gradient of a source. A limitation of this equation is it cannot be used if the distance between source and receptor is less than 10 m, in which case α_{gw} was set to unity. At each cell, if the predicted groundwater concentration was less than the measured value, the measured groundwater concentration was used.

Similar to the discussion regarding leachate adsorbing onto soil surfaces in the vadose zone, if the predicted contaminant concentration adsorbed to soil was greater than the measured value, the concentration was updated with the predicted value.

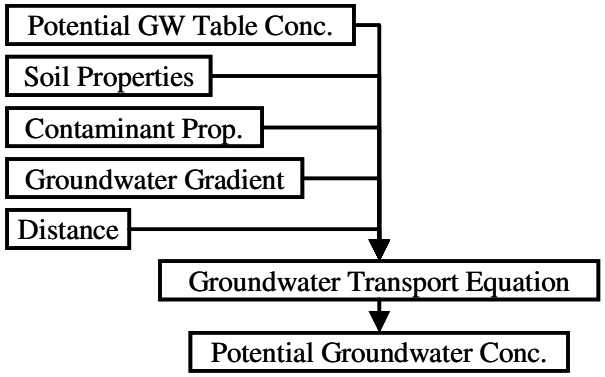

Figure 3-13 Influence diagram for potential groundwater concentration

3.2.2.5.4 Water and Wind Transport

For simplicity, the extent of contaminant transport via water or wind was assumed to be twice the distance from the centre of topsoil contamination to the edge of topsoil contamination in all directions. The assumed contaminant concentration in receiving soils was one half the weighted average of concentrations in the contaminated topsoil source zone.

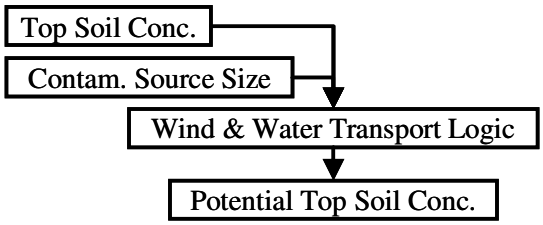

Figure 3-14 Influence diagram for potential topsoil concentrations

3.2.3 Toxicity Assessment

Health Canada (2004b, 2006b), CCME (2008a,b, 2009), and AENV (2009a) were the Canadian sources for human toxicity data and USEPA (2009c) and ORNL (2009) were the sources from the United States. Ecological receptor toxicity information was obtained from CCME (2008b, 2009), AENV (2009a), and USEPA (2009b). Human

toxicity reference values are summarised in Table B–5 and ecological toxicity reference values in Table B–6 and Table B–7, all in Appendix B.

3.2.4 Risk Characterization

3.2.4.1 Hazard Quotients

At each cell, the hazard posed by each contaminant, to each receptor, via each exposure route was expressed as a dimensionless hazard quotient, $HQ_{i,j,k,m}$, which is the measured or predicted dose divided by the tolerable dose (Suter 2007). For human and terrestrial animal receptors, $HQ_{i,j,k,m}$ was expressed as predicted daily intake, *PDI*, divided by tolerable daily intake, *TDI*. For terrestrial plants, soil invertebrates, and microorganisms, the ratio of measured or predicted soil concentration, *PSoC*, to tolerable soil concentration, *TSoC*, defined $HQ_{i,j,k,m}$. For aquatic plants and animals, $HQ_{i,j,k,m}$ was expressed as measured or predicted water concentration, *PWC*, and sediment concentration, *PSdC*, divided by tolerable water, *TWC*, and sediment concentration, *TSdC*, respectively.

The hazard quotient approach is appropriate where the dose vs. effect curve for a contaminant is not available or required (Suter 2007), as is the case with the PQRAs. Typically, hazard quotients are used to characterise the hazards associated with threshold effect contaminants (i.e. non-carcinogens) and risk values (e.g. 10^{-4} probability) used to describe non-threshold effect contaminants (HC 2004a). However, to permit combining hazards due to both carcinogenic and non-carcinogenic contaminants, the hazards associated with carcinogenic contaminants were also expressed as hazard quotients. A limitation of this simplification is carcinogenic risk values are not explicit in the calculation. If necessary, risk values can be back calculated by multiplying the

carcinogenic $HQ_{i,j,k,m}$ by the acceptable risk level of 10^{-5} (HC 2004a). A hazard quotient does not convey a likelihood or probability of an adverse effect upon a biological receptor, but is a measure of the potential for adverse effect where a higher *HQ* means a higher adverse effect potential without quantifying that potential in an absolute sense.

3.2.4.2 Hazard Indices and Cumulative Hazard Indices

Similar to the approach proposed by USEPA (2005), hazard quotients were combined across contaminants to obtain a hazard index, $HI_{i,k,m}$, for a given receptor and exposure route at each cell. Then, $HI_{i,k,m}$, values were combined across exposure routes for a given receptor to obtain a cumulative hazard index, $CI_{i,k}$, for each receptor at each cell. Finally, the maximum $CI_{i,k}$ value for each receptor was used to characterise receptor hazard, CI_k.

Equation 3-10

$$CI_k = \max\left(\sum_{m=1}^{d}\sum_{j=1}^{b} HQ_{i,j,k,m}\right)_{i=1}^{a}$$

where: i = cell "i"; j = contaminant "j"; k = receptor "k"; and, m = exposure route "m".

3.2.4.3 Combining Cumulative Hazard Indices for Ecological Receptors

Quantifying the overall hazard of a contaminated site to all 7 ecological receptors or receptor groups is confounded by the absence of a generally accepted protocol. Since cumulative hazard indices are normalised values based on tolerable doses or concentrations, a practical solution is to simply declare that a central tendency measure of CI_k values be used as estimators to characterise the set of 7 ecological receptor CI_k values for a contaminated site. Given that CI_k values can range over many orders of magnitude, the geometric mean was chosen, $aveCI_{eco}$. In cases where a particular receptor had CI_k

equal to zero, CI_k was set to a small number (i.e., 10^{-4}) that would not have a significant influence on the final result yet allow calculation of the geometric mean.

3.2.5 Scenarios

Two exposure scenarios were evaluated in the PQRAs: known and potential. In the known scenario, $knCI_k$ values were calculated for the existing combination of contaminant concentrations and their locations, current exposure routes, and land uses as supported by the ESA reports for a contaminated site. In the potential scenario, $poCI_k$ values were calculated for the potential contaminant concentrations after applying the contaminant transport models described previously and incorporating potential exposure routes within the defined land uses.

3.3 NCSCS Scoring

A NCSCS score, S_{site}, for each site was determined using the MS-Excel® worksheets and guidance provided by CCME (2008c). The objective was to test the correlation between NCSCS scores and PQRA results by referencing the same data used in completing the PQRAs.

Chapter Four: Site Data

Table 4-1 briefly summarises information on the selected contaminated sites and the following sections describe each site. Ecoregions are as defined by NRCan (2009).

Table 4-1 Selected contaminated sites

Site Id	Contaminant Source	Province or Territory	Ecoregion	Contaminant Types	Federal Step	NCSCS Class
1	Waste soil landfill	BC	Eastern Vancouver Island	Metals, PCBs, PAHs, PHCs	8	N
2	Above ground storage tank	BC	Western Vancouver Island	PAHs, PHCs	8	2
3	Weathered paint	ON	Manitoulin-Lake Simcoe	Metals	8	2
4	Mechanical repair area	BC	Coastal Gap	Metals, PAHs, PHCs	6	2
5	Above ground storage tank	YT	Ruby Ranges	PAHs, PHCs	9	2
6	Waste dump	BC	Eastern Vancouver Island	Metals, PAHs, PCBs, PHCs	7	1
7	Soak away pit	ON	St. Laurent Lowlands	CHCs	6	3
8	Salt storage area	AB	Northern Continental Divide	Salts	9	2
9	Underground storage tank	PE	Prince Edward Island	Metals, PAHs, PHCs	8	N
10	Spilled fuel	NB	Maritime Lowlands	Metals, PAHs, PHCs	7	3
11	Chemical dump	ON	St. Laurent Lowlands	CHCs, Metals, PHCs	6	1
12	Underground storage tank	ON	Thunder Bay-Quetico	PHCs	8	N
13	Above ground storage tank	MB	Aspen Parkland	PHCs	8	N
14	Underground storage tank	SK	Aspen Parkland	PHCs	6	3
15	Wastewater lagoon	SK	Aspen Parkland	PHCs	6	3
16	Pesticide dump	SK	Aspen Parkland	Metals, Phenols	6	3
17	Equipment dump	NU	Eureka Hills	Metals	6	3
18	Above ground storage tank	NT	Tazin Lake Upland	PHCs	9	N
19	Waste dump	AB	Fescue Grassland	DDT, Metals, PAHs	6	1
20	Above ground storage tank nest	NT	Tuktoyaktuk Coastal Plain	PHCs	7	1

A summary of contaminant concentration ranges is presented in Table B–8, Appendix B.

4.1 Site 1

Teranis Consulting Limited (Teranis) prepared two ESA reports (2007a,b) on behalf of Indian and Northern Affairs Canada for the non-engineered nor approved Speyside Lane Landfill. In 2006, soil from various locations in Victoria, BC was deposited at the site, which is located southwest of the Speyside Lane and East Sooke Road intersection on the Beecher Bay First Nation Indian Reserve No. 1 located at the southern end of Vancouver Island, BC. The coordinates for the site are 48.3462° N and 123.5886° W. The site is unvegetated, has no buildings, slopes slightly to the east, and has approximately 15,800 m^3 of waste soil piled across an area of approximately 0.3 hectares. The site is surrounded by hilly terrain with largely undeveloped forest except for a few residential acreages; this indicates that the site and surrounding land should be classified as parkland. The northeast portion of the site has been subjected to significant surface water runoff erosion and a small stream flows along the north and east edges of the site. The presence of brick fragments suggest that eroded soil from the site has been transported into this stream, which flows along the adjacent valley and empties into Beecher Bay located approximately 400 m south of the site.

The topsoil and surface soil is the dumped waste material containing PHCs, PAHs, metals, and polychlorinated biphenyls (PCBs) and is characterised as a mixture of silty clay, sandy silt, silt, sand, and gravel. Based on the borehole logs in the ESA reports, this soil was classified as being predominantly fine grained. The subsoil is coarse grained because the borehole logs in the ESAs characterise it as silty sand. The depth to shallow groundwater is estimated to be 2 metres below grade (mbg) and the gradient assumed to

be equivalent to topography, 0.15 m/m, toward the stream east of the site. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes but is considered suitable for domestic purposes under the potential scenario for the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 1,500 mm, there are about 3 days per year when the maximum temperature is below 0° C, and about 7 days per year when snow depth is greater than 1 cm.

4.2 Site 2

Pottinger Gaherty Environmental Consultants Ltd. (PGL) prepared a report (2006) on behalf of Indian and Northern Affairs Canada regarding a contaminated surface soil remediation caused by leaks or spills from waste oil drum that were stored on a fire station property (the site). The site is on the Quatsino Indian Reserve, Subdivision 18, which is located on Vancouver Island, British Columbia near the community of Coal Harbour. For the sake of this research, both NCSCS scoring and PQRA results were based on an assumption that the soil impacts were still present at the site.

The site coordinates are 50.6144° N and 127.5756° W. The site is unvegetated, is occupied by the fire station building, slopes to the south, and has approximately 10 m^3 of impacted soil at surface across an area of approximately 0.02 hectares. The site is adjacent to a forested area along the northwest and northeast sides of the site and residential properties along the southeast and southwest sides of the site. The site is considered commercial land use with the surrounding area as natural area to the northwest and northeast and residential to the southeast and southwest.

The topsoil, surface soil, and subsoil are characterised as coarse grained because they are gravely sand with trace cobble. The depth to shallow groundwater is estimated to be 1 mbg and the gradient assumed to be equivalent to topography, 0.06 m/m to the south. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes but is considered suitable for domestic purposes under the potential scenario for the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 2,000 mm and there are about 4 days per year when the maximum temperature is below 0° C. Data on the number of days with snow on the ground is not available.

The soil contaminants are PHCs and PAHs. Contaminant concentrations in groundwater, surface water, and sediment were not detected.

4.3 Site 3

AMEC Earth & Environmental (AMEC 2004a), Environmental Management Solutions Inc. (EMS 2004a,b), and Oliver, Mangione, McCalla & Associates (OMM 1997, 1998, 1999) prepared a total of 6 ESA reports on behalf of Fisheries & Oceans Canada regarding contaminated soil at an unattended lighthouse station on the shore of Georgian Bay near Cape Croker, Ontario. In 1998, metal impacted surface soils located around the base of the light tower were excavated and backfilled with clean fill. AMEC (2004a) noted that residual metals impacts remain below the clean backfill soil. This residual impacted soil was the subject of the NCSCS and PQRA evaluations and was estimated to have a volume of 250 m^3 across an area of about 0.03 hectares.

The coordinates for the site are 44.9560° N and 80.9605° W. The site is unvegetated and slopes toward Georgian Bay east of the site. The light tower occupies the site and a residence is still present which is periodically occupied by members of the adjacent Neyaashiinigmiing Indian Reserve 27 west of the site. The land west of the site is heavily forested without evidence of human development and slopes steeply up to a plateau overlooking Georgian Bay. North and south of the site is Georgian Bay. For the purposes of the NCSCS and PQRA evaluations, the site is considered residential land use; adjacent land west of the site is a natural area; and Georgian Bay, a waterbody.

The topsoil, surface soil, and subsoil are characterised as coarse grained because they are lacustrine sand, sandy gravel, and gravel. The depth to shallow groundwater is estimated to be 3 mbg and the gradient assumed to be 0.028 m/m, the CCME (2006) default value, toward Georgian Bay. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes but is considered suitable for domestic purposes under the potential scenario for the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 1,000 mm, there are about 69 days per year when the maximum temperature is below 0° C, and about 115 days per year when snow depth is greater than 1 cm.

The soil contaminants are metals. Contaminant concentrations in groundwater, surface water, and sediment were not detected.

4.4 Site 4

Several consultants have prepared ESA reports for the Sourdough Bay Marine Station (Azimuth *et al*. 2007, 2008; Hemmera 2001, 2002; PGL 2002). Azimuth *et al*.

(2008) reports that Sourdough Bay Marine Station is a former Fisheries and Oceans Canada base that supported conservation & protection, fish management, stock assessment, and vessel support activities. Currently, it is unoccupied and includes an administration office, workshop, a watchman's residence, storage buildings, and several other buildings. The site that was the subject of the NCSCS and PQRA evaluations is the vicinity of a wooden ramp that was used to change oil in vehicles. In the absence of other information, the topsoil is assumed to be non-vegetated. The site coordinates are 54.3271° N and 130.2780° W. The site is bounded to the south and east by Sourdough Bay and Fern Passage to the north and northeast. The remaining site bounds are the balance of the Marine Station to the west and a heavily forested area beyond the Station.

The topsoil, surface soil, and subsoil are characterised as coarse grained because they are characterised as a heterogeneous fill mixture of silt, sand, gravel and underlain by native beach sand and cobble. The depth to groundwater is likely influenced by changes in ocean tides and is estimated to be 1 mbg with the gradient assumed to be the default CCME (2006) value of 0.028 m/m toward the ocean to the east. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, or irrigation purposes. Given the site's proximity to the ocean, groundwater is likely saline but is conservatively assumed to be suitable for domestic purposes under the potential scenario for the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 2,600 mm, there are about 10 days per year when the maximum temperature is below 0° C, and about 28 days per year when snow depth is greater than 1 cm.

Azimuth *et al.* (2008) noted that the wooden ramp is approximately 8 m long by 3 m wide by 1 m high indicating the approximate extent of source zone contamination. The contaminants are PHCs, PAHs, and metals.

4.5 Site 5

Jacques Whitford and SNC Lavalin Morrow Environmental prepared a total of 4 ESA reports (JWL 2006; SNC 2007, 2008a,b) on behalf of the Royal Canadian Mounted Police regarding contaminated soil at a RCMP detachment in Haines Junction, Yukon. The legal location is Lots 7 to 12, Block 5, CLSR No. 41519, Haines Junction, Yukon Territory. SNC (2008a) reported that the detachment is located at the southwest corner of the intersection between the Alaska and Haines Highways and consists of the detachment building, a parking area, a grass covered yard surrounded by a fence, and the garage building. The site surface is partially vegetated and flat with topography in the area generally slopes gently to the Dezadeash River located approximately 600 m south of the site. The site coordinates are 60.7519° N and 137.5111° W. The contaminant location is considered commercial land use and is surrounded by businesses to the north and east and adjacent residential properties to the south and west.

PHC and PAH contaminated soil, covering an approximate 5 m by 5 m area, due to a fuel oil AST adjacent to the garage building was the subject of the NCSCS and PQRA evaluations. Although the impacted soil has been excavated, for the purposes of the evaluations the impacted soil was assumed to be still in place.

The topsoil is a sandy fill material and considered coarse grained. Surface soil and subsoil are characterised as fine grained because they are described as medium plastic clay. The depth to groundwater was not found during subsurface investigations and was

assumed to be at 6 mbg, the approximate depth of the deepest monitoring well installed at the site. Groundwater gradient is estimated to be 0.044 m/m south toward the river. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, or irrigation purposes but is assumed to be suitable for domestic purposes under the potential scenario for the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 300 mm, there are about 120 days per year when the maximum temperature is below 0° C, and about 174 days per year when snow depth is greater than 1 cm.

4.6 Site 6

SEACOR (2006a,b) conducted 2 ESAs on behalf of Indian and Northern Affairs and provides a description of the site:

> "An unauthorised waste disposal facility...has been operated on Snuneymuxw First Nation (SFN) Indian Reserve 2...for approximately 15 years...Most of the waste deposited at the site, based on visual observations and anecdotal reports, has been demolition and construction debris; however, a number of other waste types have also been evident, e.g. computers, fridges, auto parts, paint wastes, and tires."

The site is unvegetated and has approximately 3,700 m^3 of buried waste soil across the site. The site is located at 1550 Clifford Road near Nanaimo, British Columbia and is approximately 6.5 hectares on the bank of the Nanaimo River in an agricultural area. North and west of the Site are forested land. The east edge of the Site is bordered by the Nanaimo River and the south edge by a farm and farm houses. The site coordinates are 49.1211° N and 123.8883° W.

The topsoil, surface soil, and subsoil in the waste area are coarse grained material and is characterised as fill soil mixed with waste material. Outside of the waste area, soil is considered fine grained because soil texture is silt and sandy silt. The depth to shallow groundwater is approximated as 0.3 metres mbg and the gradient 0.034 m/m to the southeast based on measurements. Groundwater adjacent to the site is used for domestic and livestock watering purposes. Under the potential scenario, groundwater beneath the site is considered suitable for both domestic and livestock watering purposes.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 1,200 mm, there are about 3 days per year when the maximum temperature is below 0° C, and about 19 days per year when snow depth is greater than 1 cm.

The contaminants are phenols, cresols, cyanide, dioxin & furans, PCBs, PHCs, PAHs, metals, and other inorganics.

4.7 Site 7

Franz (2005, 2006) prepared 2 ESA reports regarding contamination at Natural Resources Canada's Bells Corner Complex (BCC) located at 4 Haanel Drive, Ottawa, Ontario. The BCC is a research and testing facility that focuses in the areas of fuels, combustion, and explosives and consists of approximately 20 buildings located on a portion of 170 hectares of land. Area 21 is the site and is a former soak away pit having an approximate size less than 5 m by 5 m and adjacent to Building 1. The site and surrounding area is considered commercial land use in the NCSCS and PQRA evaluations. The site is vegetated and flat with topography in the vicinity gently slopes to the west. The site coordinates are 45.3204° N and 75.8674° W.

Soil stratigraphy consists of approximately 2 m of medium to coarse sand fill underlain by fractured sandstone and dolostone, all classified as coarse grained material. The assumed groundwater depth is 3 mbg and the measured gradient to the west of 0.015 m/m. Groundwater beneath the site is currently not used for domestic, livestock, or irrigation purposes. Under the potential scenario, groundwater beneath the site is considered suitable for domestic purposes.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 900 mm, there are about 81 days per year when the maximum temperature is below 0° C, and about 122 days per year when snow depth is greater than 1 cm.

The contaminants are the chlorinated hydrocarbons (CHCs) tetrachloroethene, trichloroethene, and vinyl chloride in groundwater. Soil, surface water, or sediment contamination was not detected.

4.8 Site 8

Meridian (2006), Parks Canada (2007), and JASA (2007) have prepared ESAs and related information on behalf of Parks Canada for this location. The Site is within Waterton National Park, Alberta and is a former sand and salt stockpile area located on the Blakiston Creek alluvial fan approximately 500 m from the north shore of Middle Waterton Lake. The coordinates for the site are 49.0681° N and 113.8633° W. The Site is not vegetated but is surrounded by forest and slopes gently toward Middle Waterton Lake. Soil is gravel and cobble and groundwater is approximately 2 mbg.

JASA (2007) reported that approximately 1,600 tonnes or roughly equivalent to 800 m^3 of salt contaminated gravely soil was removed. Although the contamination has been removed, the NCSCS and PQRA evaluations assume it is still in place. The specific

contaminants or parameters of concern are sodium, chloride, sodium adsorption ratio, and soil electrical conductivity.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 800 mm and there are about 50 days per year when the maximum temperature is below 0° C.

Under the known or current scenario, the selected land use is natural area because the location is assumed to be rarely frequented by humans and groundwater is assumed not to be used for domestic, livestock watering, or irrigation purposes. However under the potential scenario, agricultural land use was selected to include the possibility of human occupancy and livestock grazing. All three groundwater uses were also assumed under the potential scenario.

4.9 Site 9

Jacques Whitford Environment Limited prepared an ESA report (JWEL 2002) on this site for Public Works and Government Services Canada. The Site is a Canadian Coast Guard Base along the shore in downtown Charlottetown, Prince Edward Island at 1 Queen Street. The property identification number is 335158 and the site coordinates are 46.2308° N and 63.1228° W. Potential environmental concerns associated with the Site include underground petroleum storage tanks, a former scrap yard, impacted harbour bottom sediments, imported fill material of unknown quality, and former coal storage activities. The site is considered a commercial land use and is also surrounded by commercial properties, being downtown businesses.

The surface is bare gravel and thus considered coarse grained. Surface soil and subsoil are also characterised as coarse grained because they consist of a combination of

silty sand, sand, gravel, and cobble. The depth to groundwater is governed by the harbour tide level and was approximated to be 2 mbg. Groundwater gradient was estimated to be 0.045 m/m toward the harbour. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes and was not foreseen to be used for these purposes in the future.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 1,200 mm, there are about 75 days per year when the maximum temperature is below 0° C, and about 122 days per year when snow depth is greater than 1 cm.

The contaminants are PHCs, PAHs, and metals.

4.10 Site 10

Jacques Whitford and Associates Limited (1991, 1993) and AMEC Earth & Environmental (2004b, 2008) prepared a series of reports on behalf of Transport Canada regarding an aircraft firefighting training area (FTA) at the Greater Moncton International Airport near Dieppe, New Brunswick. The site is located within the "V" shape created by the two runways and its coordinates are 46.1106° N and 64.6769° W. The site and adjacent land is considered industrial land use because of the site's restricted access.

The site was used for firefighting training from 1953 to 1990 and included a mock airplane that was flooded with 7 m^3 to 14 m^3 of gasoline, the gasoline ignited, and then extinguishing as part of a training event. An attempt to burn off residual gasoline was performed by reigniting the fuel and letting the fire extinguish itself. The FTA was decommissioned in 1992 and environmental site assessment activities began in the same

year. These assessments determined that approximately 700 m^3 of petroleum hydrocarbon contaminated soil remains across 0.07 hectares.

The Site is flat, vegetated, and is surrounded by a drainage ditch that gathers groundwater and is connected to a wetland approximately 900 m north of the Site. The topsoil, surface soil, and subsoil are characterised as coarse grained because they are sand and gravel fill as well as underlying sand till. Groundwater is within 1 mbg, is hydraulically connected to the water in the drainage ditch to the north, and has a measured gradient of 0.042 m/m to the north. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes nor are they considered for these purposes under the potential scenario in the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 1,200 mm, there are about 74 days per year when the maximum temperature is below 0° C, and about 119 days per year when snow depth is greater than 1 cm.

4.11 Site 11

Jacques Whitford Environmental Limited (1998) and AMEC Earth and Environmental (2005) prepared a pair of ESA reports for the Communications Research Centre (CRC) located at 3701 Carling Avenue, Ottawa, Ontario on behalf of Industry Canada. AMEC (2005) provides an interesting historical summary of the property and the site in question, which is excerpted here:

> "[The CRC] was established between 1951 and 1953 to conduct major portions of the Chemical Defence Program of the Department of National Defence (DND)...[This program] included the production of respirators..., along with research projects on flamethrower fuel, chemical-

> warfare protective clothing and synthesis of materials for oxidation of carbon monoxide. The research program also included the synthesis of toxic chemicals...During most of the period 1952 to 1980, there were no official waste disposal sites for materials such as nerve agent or their residues, therefore disposal pits were used at the CRC/DREO site to control chemical and biological waste disposal from the laboratories. During the history of the site from 1952 to 1988 there were five areas used for chemical waste disposal pits...A large rock was placed in the centre of the pit, this was used to break glass bottles of chemicals sent to the pit. Super toxic chemicals...were typically neutralised in the laboratory prior to being disposed in the pit. The materials disposed were left to weather for 3 to 6 months, then the contents were burned off by pouring diesel fuel on the contents and igniting it... There were no records kept on what was disposed, whether it had been neutralised or not, how much and when it was disposed. Recent discoveries at the site indicated that not all of the safe practices for the pits may have been followed."

Area 1 is one such former disposal pit, estimated to contain about 5,700 m^3 of contaminated soil, located along the south property line of the CRC at 45.3468° N and 75.8897° W. The site is partially vegetated, is approximately 50 m from adjacent buildings, and slopes slightly to the northeast towards the Ottawa River located 2 km away. The site is surrounded by the remainder of the unforested CRC to the northwest, north, northeast and east and by off property, treed land to the southeast, south, southwest, and west. For the known scenario, the site was classified as commercial land use but was considered agricultural land under the potential scenario because the City of Ottawa subzoning is *RC10 – Greenbelt Employment Areas*, which permits agricultural uses.

The topsoil, surface soil, and subsoil are all classified as coarse grained material since collectively they are characterised in the ESAs as sandy fill, sand, silty clay all

overlying limestone bedrock. The depth to shallow groundwater is estimated to be 2 mbg and the gradient assumed to be equivalent to topography, 0.015 m/m, toward the Ottawa River northeast of the site. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes but is considered suitable for domestic and livestock watering purposes under the potential scenario for the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 900 mm, there are about 81 days per year when the maximum temperature is below 0° C, and about 122 days per year when snow depth is greater than 1 cm.

The contaminants are PHCs, CHCs, and metals.

4.12 Site 12

Wardrop Engineering Inc. (1997) prepared an ESA on behalf of Transport Canada regarding PHC contaminated soil at a flying school at the Thunder Bay International Airport. It reported that:

> "Two underground storage tanks (USTs) existed at the [site] during the 1970s and 80s. One of the USTs was reportedly abandoned in 1975 because of a suspected leak. The two tanks were reportedly removed along with some soil in 1993 and one new 22,700 L Av-gas tank was installed within the excavation. No documented information was found to confirm the presence of a leaky tank or the tank removal program."

The site location is 498 John Paterson Drive, Thunder Bay, Ontario and the site coordinates are 48.3688° N and 89.3155° W. The site is an industrial land use because it is within a restricted area at the airport.

The site surface is flat and covered by asphalt and gravel. Topsoil, surface soil, and subsoil collectively consist of a sand and gravel fill to about 3.8 mbg and are

characterised as coarse grained. The depth to groundwater was approximated as 0.3 mbg with a 0.025 m/m gradient to the east toward Lake Superior. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes nor is it expected to be used for these purposes in the future given the industrial land use.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 700 mm, there are about 101 days per year when the maximum temperature is below 0° C, and about 136 days per year when snow depth is greater than 1 cm.

4.13 Site 13

On behalf of Agriculture and Agri-Food Canada, KGS Group prepared two ESA reports (2002, 2003b) on the PFRA's Ellice-Archie Community Pasture and Bull Station located approximately 8 km north of McAuley, Manitoba. The Station's legal land description is the Southeast Quarter of Section 14, Township 16, Range 29, West of the 1st Meridian and the site coordinates are 50.3619° N and 101.3673° W.

KGS (2003) reported that the station has been used to graze cattle since 1936 (i.e., agricultural land use). The site that is the subject of the NCSCS and PQRA evaluations is the gasoline and diesel above ground storage tanks (i.e., PHCs) located south west of the bull corral. Beaver Creek is located approximately 150 m north of the site and a potable groundwater well located approximately 75 m northeast of the site.

The site surface is flat and bare to partially vegetated. Topsoil, surface soil, and subsoil are a combination of silty, gravely sand and silty sand that are typical of a creek valley and is characterised as coarse grained material. The depth to groundwater is approximately 4 mbg with a measured 0.005 m/m gradient to the northeast toward Beaver

Creek. As previously mentioned, groundwater at approximately 75 m northeast of the site is drawn for domestic purposes and is assumed to also be used to water livestock. Under the potential scenario, groundwater beneath the site is assumed to be used for both domestic and livestock watering purposes.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 500 mm, there are about 115 days per year when the maximum temperature is below 0° C, and about 132 days per year when snow depth is greater than 1 cm.

4.14 Sites 14 to 16

Environmental site assessment reports for the PFRA Indian Head Shelterbelt Centre (Shelterbelt Centre) were among the first reports to be received via the Access to Information requests and evaluated. To expedite data analysis using available information, the author identified and evaluated three contaminated sites at this location: the area around a former UST nest, two lagoons, and a non-engineered landfill. Information common to all three sites is summarised as followed and site specific information presented in the subsequent three sub-sections.

Golder Associates Ltd. (2001) and KGS Group (2003a) prepared a pair of ESA reports for the Shelterbelt Centre on behalf of Agriculture and Agri-Food Canada. The Shelterbelt Centre is an agriculture research station and tree nursery located approximately 2 km south of the Town of Indian Head, Saskatchewan at Section 11, Township 18, Range 13, West of the 2nd Meridian.

The topography at all three sites is flat and soil is characterised as fine grained being clay till with small sand lenses. Since potable water is supplied by the nearby Town

of Indian Head, groundwater is not used for domestic, livestock watering, or irrigation purposes. However, these purposes are considered valid under the potential PQRA scenario.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 400 mm, there are about 19 days per year when the maximum temperature is below 0° C, and about 126 days per year when snow depth is greater than 1 cm.

4.14.1 Site 14

The site coordinates are 50.5086° N and 103.6882° W. Two gasoline and one diesel underground storage tanks (USTs) were formerly located south of the main shop building and were removed in 2001. Residual hydrocarbon contamination was subsequently discovered and delineated and the estimated volume of contamination is 2,400 m^3 (i.e., 480 m^2 by 5 m deep). PHCs were the contaminants.

4.14.2 Site 15

The site coordinates are 50.5064° N and 103.6924° W. The site is groundwater in the vicinity of two lagoons used to collect wastewater and surface runoff from the Shelterbelt Centre. In the past, the groundwater was analyzed for agricultural chemicals and all results were non-detect. More recently, the groundwater was sampled for petroleum hydrocarbons and impacts were identified.

4.14.3 Site 16

The site coordinates are 50.4994° N and 103.6841° W. A former agricultural chemical dump is located near the southeast property line of the Shelterbelt Centre. In the early 1970's, expired agri-chemical were enveloped in concrete and placed in an excavation that was subsequently backfilled with clay. Subsequent groundwater sampling

in 2001 and 2002 did not detect pesticides but did detect metals and petroleum hydrocarbons. The estimated volume of soil contamination is 40 m^3. PHCs, phenols, and metal are the contaminants.

4.15 Site 17

Royal Military College (RMC 2001) and National Research Council of Canada (NRCC 2007 & 2008) prepared 3 ESA reports on behalf of National Defence regarding a dump near Canadian Forces Station (CFS) Alert, Ellesmere Island, Nunavut. The site is located at 82.4883° N and 62.3492° W and is an inactive dump site about 0.5 hectares in size. It is located at the end of Line Road to the southwest of the CFS Alert station, and is positioned on a slope approximately 200 m west of Alert Inlet. Remaining debris at the site suggests that it was used to discard vehicle parts, wire, and other metal. Soils analysis showed that there were lead and zinc concentrations exceeding the referenced CCME guidelines.

There is a drainage channel that drains the site to Alert Inlet. For the purposes of the NCSCS and PQRA evaluations, the site is considered an industrial land use because of the ongoing operations of CFS Alert and the geographical restrictions to accessing the site.

Soil at the site is considered coarse grained because it is characterised as coarse shale stone. The depth to shallow groundwater at is estimated to be 3 mbg however the soil is permafrost meaning lateral contaminant in groundwater transport is expected to be low. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes and is not considered suitable for these purposes in the future.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 150 mm, there are about 288 days per year when the maximum temperature is below 0° C, and about 306 days per year when snow depth is greater than 1 cm.

4.16 Site 18

Bryant Environmental Consultants Ltd. prepared an ESA report (2003) for Public Works and Government Services Canada regarding a small contaminated soil remediation at a residential complex in Yellowknife, Northwest Territories. The site is a former fuel oil above ground storage tank that was located in the crawl space beneath the main floor of 982 Sissons Court, Yellowknife. The site coordinates are 62.4427° N and 114.3861° W.

The soil beneath the site is assumed to be coarse grained soil in the absence of information in the ESA report. The depth to groundwater was not found during the soil remediation and the CCME (2006) default value of 3 mbg was assumed. Based on topography, groundwater gradient is estimated to be 0.020 m/m to the southeast. Groundwater beneath and adjacent to the site is not used for domestic, livestock, nor irrigation purposes since the site is supplied by the City of Yellowknife's water distribution network. However, domestic use of groundwater was assumed under the potential scenario for the PQRAs.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 300 mm, there are about 175 days per year when the maximum temperature is below 0° C, and about 191 days per year when snow depth is greater than 1 cm.

4.17 Site 19

Jacques Whitford Limited (2004) and Meridian Environmental Inc. (2007a,b) prepared 3 ESA reports on behalf of Parks Canada for the non-engineered nor approved Bar U Ranch Waste Disposal Midden 1. Bar U Ranch is a National Historic Site located about 13 km south of Longview, Alberta. Waste Midden 1 (the site) is approximately 8 m by 40 m and is located on a hillside overlooking the ranch's north pasture and is approximately 300 m from Pekisko Creek located south of the Site, which flows through the ranch. The midden was a dump site for the ranch from the early 1900's to around 1990 and may have contained waste oil and fuel containers, pesticide and herbicide containers, glycol, batteries, creosote and chromated copper arsenate (CCA) treated wood, metal waste, vehicles, and paint cans (Meridian 2007a). The assessed contaminants are PAHs, metals, and DDT. The coordinates for the site are 50.4256° N and 114.2513° W.

The topsoil and surface soil is characterised as sandy and silty clay, which is considered fine grained. The subsoil is coarse grained because the borehole logs in the ESAs characterise it as weathered siltstone bedrock. The depth to shallow groundwater is estimated to be 3 metres below grade (mbg) and the gradient assumed equivalent to topography, 0.070 m/m, toward Pekisko Creek southeast of the site. Groundwater in the vicinity of the site is currently used for domestic and livestock watering purposes and is considered suitable for domestic, livestock, and irrigation purposes under the potential scenario.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 500 mm, there are about 59 days per year when the maximum temperature is below 0° C, and about 88 days per year when snow depth is greater than 1 cm.

4.18 Site 20

UMA Engineering Ltd. (2008) completed a report on behalf of Public Works and Government Services Canada regarding the remediation of a petroleum storage and handling area at the former Bar D Distant Early Warning (DEW) line facility at Atkinson Point, located on the northern coast of the Tuktoyaktuk Peninsula in the Northwest Territories. This facility included personnel modules, garages and warehouse, antennae, petroleum-oil-lubricant (POL) storage tanks, roads, and an airstrip. The site which is the subject of this NCSCS worksheet is the area of the former POL storage tanks located adjacent to Louth Bay. The site has been decommissioned and remediation of hydrocarbon impacts has occurred and the focus is the residual soil impacts. The coordinates for the site are 69.9420° N and 131.4201° W.

The site is vegetated, has no buildings, and slopes slightly toward Louth Bay. Approximately 0.13 ha of residual PHC impacted soil is expected to be present based on the remediation footprint previously excavated.

The soil is beach sands based on the ESA reports and is considered coarse grained. The depth to shallow groundwater is estimated to be 1 metre below grade (mbg) and equivalent to the ocean level. Groundwater beneath and adjacent to the site is not presently used for domestic, livestock, nor irrigation purposes nor is it considered suitable for these purposes under the potential scenario for the PQRAs, given the natural land use of the site.

Based on Environment Canada (2010) data, the average annual precipitation is approximately 200 mm, there are about 228 days per year when the maximum temperature is below 0° C, and about 238 days per year when snow depth is greater than 1 cm.

Chapter Five: A Comparison of Human Health & Ecological Risk Assessment Results for Contaminated Sites

5.1 Introduction

Human health and ecological risk assessment frameworks in North America have been developed and refined over the past three decades (USEPA 2008). Health Canada describes a preliminary quantitative risk assessment (PQRA), in the context of human receptors, as a screening assessment that uses "prescribed methods and assumptions that ensure that exposures and risks are not underestimated" (2004a). The Canadian Council of Ministers of the Environment (CCME) describes a screening ecological risk assessment as a tier 1 risk assessment "based primarily on data from literature, previous or preliminary studies of the contaminated site, monitoring studies, historical data of the site, and a reconnaissance visit to evaluate the receptors, exposure, hazards, and risk at the site" (1996). For the purposes of this research, both screening human health and ecological risk assessments are referred to as a PQRA. The focus is a cross analysis of human health risk assessment and ecological risk assessment results for contaminated sites to examine how they are related. This analysis will help assessors answer questions such as:

- Can one receptor act as a surrogate for all other receptors?
- When conducting a PQRA, must all receptors be assessed directly?

We have used data on 20 contaminated sites located across the country to conduct this analysis.

5.2 Methods

Both Health Canada (2004a) and CCME (1996, 1997) identify the major elements of a PQRA as: problem formulation (or conceptual site model), exposure assessment, hazard (or toxicity) assessment, and risk characterization. This structure was adopted in discussing the details of the PQRAs applied here.

5.2.1 Conceptual Site Model

5.2.1.1 Biological Receptors

Biological receptors identified by CCME (2006) were used in the PQRAs. The relevant human receptors are the toddler, aged 7 months to 4 years old, for threshold effect contaminants and an adult, a person 18 years old or greater, for non-threshold effect contaminants (e.g. carcinogens) (HC 2004a). In addition, First Nations toddlers and adults were considered sensitive human receptors because Health Canada (2004a) has concluded that in general they have greater dependence on local fish and game compared to the overall Canadian population.

Guidelines published by Alberta Environment (AENV 2009a,b) are based on CCME (2006) guidance and have identified the following ecological receptors groups:

- terrestrial plants and soil invertebrates;
- soil microorganisms responsible for nutrient and energy cycling;
- agricultural livestock;
- wildlife including primary, secondary, and tertiary consumers; and,
- aquatic life.

Consistent with CCME (2006, 2008a,b) and AENV (2009a), a dairy cow was used as the surrogate ecological receptor for livestock because toxicity data is readily available and

because of the cow's "economic importance" (AENV 2009a). Similarly, CCME and AENV consider the meadow vole (*Microtus pennsylvanicus*) to be the surrogate, primary consumer, mammal species in developing soil remediation guidelines because of its high soil ingestion rate relative to its low body weight. Given its widespread distribution across Canada (Bernhardt 2009), the meadow vole was used as a surrogate species in the PQRAs.

Based on CCME (2006) guidance, we applied the following food chain when assessing the effect of bioaccumulating contaminants: soil → earthworm → secondary consumer → tertiary consumer. Earthworms have a high soil ingestion rate relative to body weight and are assumed to retain high residual contaminant concentrations in their tissue. This concentration is then directly available to secondary consumers. Consistent with CCME (2008b), the masked shrew (*Sorex cinereus*) was the surrogate secondary consumer chosen for the PQRAs because it is an insectivore that preys on earthworms and has a widespread distribution across Canada (Bernhardt 2009). The American kestrel (*Falco sparverius*) was the chosen surrogate, tertiary consumer used in the PQRAs because it includes small mammals, such as shrews, in its diet (USEPA 1993) and because this species has wide spread distribution through Canada (Bernhardt 2009). This species is referenced in soil quality guidelines published by federal (EC 1999, 2001) and provincial environmental agencies (OMOE 2008).

5.2.1.2 Coordinate System and Soil Strata

A polar coordinate system was used to spatially reference contaminated site data in ESA reports and was selected to simplify contaminant transport calculations. The origin was positioned within the contaminant source zone where the majority of detected

contaminants were at their maximums. A site was then divided into cells, $i_{\theta,r}$, each identified by its direction, θ, and radius from the origin, r. The 8 cardinal and ordinal directions (e.g., N, NE, E,…) were referenced for simplicity. Radii in metres were selected based on the following quasi-logarithmic series: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600, 700, 800, 900, & 1,000. At each cell, soil was divided vertically into three strata where topsoil was defined as the top 0.3 m, surface soil as between 0.3 metres and 1.5 metres below ground surface (mbgs), and subsoil below 1.5 mbgs. The surface soil and subsoil depth definitions are consistent with definitions proposed by CCME (2006). The demarcation between unsaturated and saturated soil was site specific depending on measured or assumed shallow groundwater depth. Where a cell corresponded to a water course or water body, soil strata were not defined and the cell was called “water”.

In each cell, soil strata were characterised as coarse grained or fine grained using the definition and default soil properties provided by CCME (2006). Similarly, CCME default values were applied for unsaturated and saturated soil. Saturated soil was also divided into frozen or not frozen to account for permafrost regions.

Topsoil was also classified as being either impervious, such as asphalt or concrete; bare soil, meaning no vegetation; partially vegetated, meaning approximately half of the soil surface covered by plant growth; and fully vegetated. Along with soil texture, these topsoil characteristics were important in estimating precipitation infiltration rates and wind generated, air borne particulate concentrations.

At each cell, each measured contaminant concentration in soil was assigned to one of the three defined soil layers: topsoil, surface soil, and subsoil. If more than one result was available per cell layer, the maximum result was used. Groundwater results were assigned to the saturated zone and the most recent result used.

The schematic in Figure 5-1 illustrates the coordinate system's cells and how the cell grid was overlaid upon a contaminated site. The grey ellipse represents a contaminant source zone with a plume and the black dots represent sample locations within the cells.

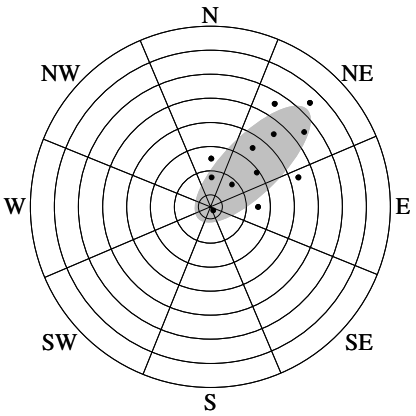

Figure 5-1 Polar coordinate system

5.2.1.3 Land Uses

Each cell was assigned one of seven land uses to determine the relevant receptors and exposure parameters. The following land uses as defined by CCME (2006) were used in the PQRAs: agricultural, residential, parkland, commercial, and industrial. In addition to the CCME land uses, a natural area land use as defined by AENV (2009a) was used in the PQRAs to accommodate contaminated sites located in remote areas not expected to be occupied by humans. Finally, areas capable of sustaining an aquatic ecosystem, meaning fish, aquatic plants, and invertebrates, were defined as "water". Table 5-1 summarises the seven land uses and corresponding receptors. The selection of land use(s)

for a site was based on information in the associated environmental site assessment (ESA) reports, aerial imagery, and land use zoning maps, where available.

Table 5-1 Land use receptors

Receptor	Land Use						
	Nat	**Agri**	**Resi**	**Park**	**Com**	**Ind**	**Wat**
Human toddler	-	Yes	Yes	Yes	Yes	-	-
Human adult	-	Yes	Yes	Yes	Yes	Yes	-
Terrestrial plant & soil invertebrates	Yes	Yes	Yes	Yes	Yes	Yes	-
Soil microorganisms	Yes	Yes	Yes	Yes	Yes	Yes	-
Cow	-	Yes	-	-	-	-	-
Meadow vole	Yes	Yes	Yes	Yes	-	-	-
Masked shrew	Yes	Yes	Yes	Yes	-	-	-
American kestrel	Yes	Yes	Yes	Yes	-	-	-
Aquatic Life	-	-	-	-	-	-	Yes

5.2.1.4 Additional Cell Attributes

Additional cell attributes were the presence or absence of habitable buildings, types of groundwater usage, and the presence or absence of sensitive human receptors. The presence of buildings intended for human occupancy located on contaminated soil or groundwater creates potential for indoor air quality issues for occupants due to contaminant vapours infiltrating the building. Contaminated groundwater used for potable water, livestock watering, or crop irrigation increases risk to human and livestock receptors as well as irrigation crop production.

5.2.1.5 Meteorological Data

Data on annual precipitation and the number of days with a temperature below zero Celsius were necessary to estimate water infiltration rate via the vadose zone and the biodegradation rate of contaminants in the vadose zone, respectively. Environment

Canada (2008b) meteorological data was obtained from a weather station in the vicinity of each contaminated site.

5.2.2 Exposure Assessment

5.2.2.1 Chemical Properties

Information on the following chemical properties was needed to predict how contaminants behaved and are transported through and across media: organic carbon partitioning coefficient, K_{oc}; distribution coefficient, K_d; dimensionless Henry's constant, H'; molecular diffusion coefficients in air, D_a, and water, D_w; aqueous solubility, S; vapour pressure, p_v; and molecular weight, M_w. In addition, information on the following chemical parameters were needed: half life in vadose and saturated zones, $t_{1/2us}$ and $t_{1/2s}$; absorption factors for human gastrointestinal tract, AF_G; lungs, AF_L; and skin, AF_S; and biotransfer factors to beef, B_b; milk, B_m; plants and produce, k_1 to k_3; and earthworms & small mammals, k_4 to k_6;. Data was obtained from the following sources: AENV (2009a), Baes *et al*. (1984), BCMELP (1996), CCME (2008a,b, 2009), Gustafson *et al*. (1997), Health Canada (2004a), Mackay *et al*. (2006), ORNL (2009), Travis & Arms (1988), and USEPA (1996, 2005, 2009a,b).

5.2.2.2 Exposure Routes & Durations

Table 5-2 summarises the exposure route for each of the previously identified receptors and is based on information provided by CCME (2006) and AENV (2009a). Exposure durations, physiological parameters, and media or food specific exposure parameters for human receptors were obtained from Health Canada (2004a) and CCME (2006). Ecological receptor exposure assumptions in Table 5-3 are based on guidance provided by CCME (2006) and AENV (2009a) with input from USEPA (1997).

Table 5-2 Exposure routes

Receptor	Contaminated Medium	Exposure Route		
		Ingestion	Inhalation	Contact
Human	Topsoil	Yes	-	Yes
	Surface soil	Yes	-	Yes
	Groundwater	Yes	-	-
	Particulate	-	Yes	-
	Indoor air	-	Yes	-
	Beef	Yes	-	-
	Milk	Yes	-	-
	Produce	Yes	-	-
Plants & invertebrates	Topsoil	-	-	Yes
	Surface soil	-	-	Yes
	Irrigation water	-	-	Yes
Soil microorganisms	Topsoil	-	-	Yes
	Surface soil	-	-	Yes
Cow	Topsoil	Yes	-	-
	Water	Yes	-	-
	Plants	Yes	-	-
Meadow vole	Topsoil	Yes	-	-
	Surface soil	Yes	-	-
	Plants	Yes	-	-
Masked shrew	Topsoil	Yes	-	-
	Surface soil	Yes	-	-
	Earthworm	Yes	-	-
American kestrel	Topsoil	Yes	-	-
	Masked shrew	Yes	-	-
Aquatic Life	Surface water	-	-	Yes
	Sediment	-	-	Yes

Table 5-3 Ecological receptor exposure parameters

Parameter	Unit	Receptor			
		Cow	Meadow Vole	American Kestrel	Masked Shrew
Body weight, *BW*	kg	550	0.017	0.124	4.5×10^{-3}
Air inhalation rate, IR_a	m^3/d	85.0	0.0623	0.0820	7.24×10^{-3}
Water ingestion rate, *WIR*	kg/d	100	3.57×10^{-3}	0.0146	7.65×10^{-4}
Soil ingestion rate, *SIR*	kg/d	0.747	5.79×10^{-5}	-	1.94×10^{-5}
Food ingestion rate, *FIR*	kg_{dw}/d	8.60	2.41×10^{-3}	0.011	8.09×10^{-4}

5.2.2.3 Dose Equations

Human exposure equations provided by Health Canada (2004a) were used in calculating predicted daily intake (*PDI*) values, with units $mg \cdot kg_{bw}^{-1} \cdot d^{-1}$, at each cell via soil ingestion, particulate inhalation, vapour inhalation, water ingestion, soil contact with skin, and contaminated food ingestion. Figure 5-2 summarises the input data required to calculate doses.

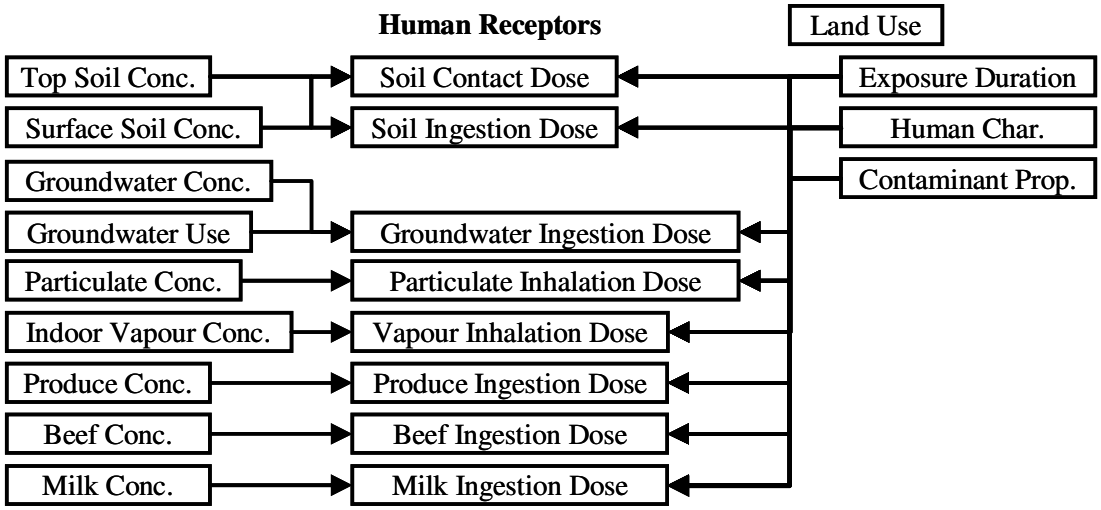

Figure 5-2 Influence diagram for human receptor dose calculations

The soil contact doses, having units of mg/kg, for plants & soil invertebrates and soil microorganisms were determined from the maximum of measured topsoil and surface soil concentrations. An irrigation water contact dose was also calculated for plants, specifically crops and produce, where an agricultural land use was present (CCME 2006). The contaminant concentration in irrigation water was assumed to be the same as in groundwater within the same cell. Figure 5-3 summarises the input data required to calculate doses.

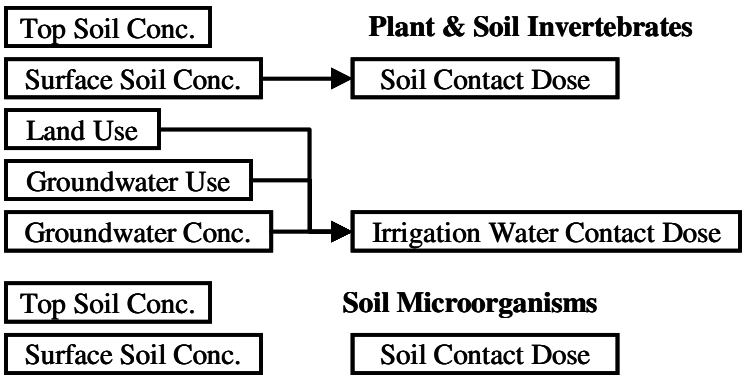

Figure 5-3 Influence diagrams for plant & invertebrate and soil microorganism dose calculations

Primary consumer *PDI* equations for contaminated soil, water, and plant food exposure were used to calculate doses for the cow and meadow vole (CCME 2006):

Equation 5-1 $$PDI_{Ing} = C \times IR \times BF / BW$$

where:

- PDI_{Ing} = predicted daily intake via soil ingestion, water ingestion, or food ingestion ($mg \cdot kg_{bw}^{-1} \cdot d^{-1}$);
- C = measured maximum contaminant concentration in soil, water, or food (mg/kg);
- IR = receptor specific soil, water, and food ingestion rate, respectively (kg/d);
- BF = contaminant bioavailability factor, conservatively set to 1; and,
- BW = receptor body weight (kg).

In Equation 5-1, the contaminant concentration in topsoil was used for the cow and the maximum of topsoil and surface soil concentrations for the meadow vole. Refer to Figure 5-4 for the respective dose calculation influence diagrams.

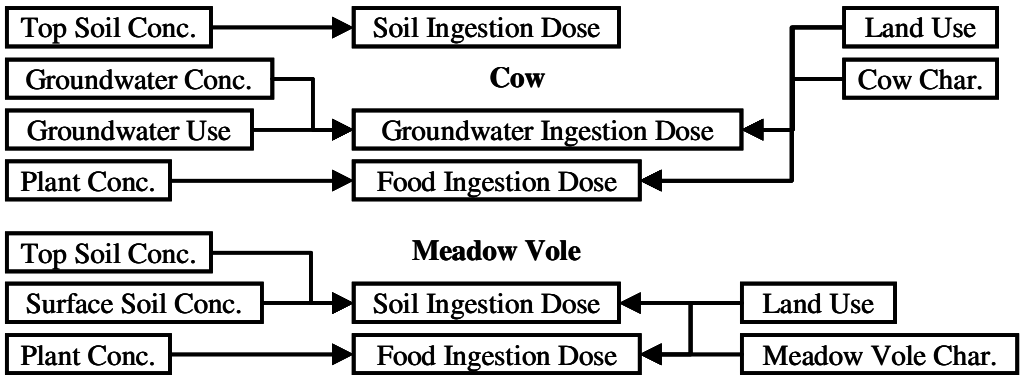

Figure 5-4 Influence diagram for cow and meadow vole dose calculations

Secondary and tertiary consumer equations *PDI* equations for contaminated soil and food exposure were used to calculate doses for the masked shrew and American kestrel, respectively (CCME 2006). The contaminated food sources for the shrew and kestrel were the earthworm and masked shrew, respectively.

Equation 5-2 $$PDI = C \times IR \times BF \times AF_{fr} \times AF_e / BW$$

Variables are as defined previously with the addition of the proportion of a consumer's foraging range within contaminated site, AF_{fr}, and proportion of time that a consumer spends on the contaminated site, AF_e. Both variables were conservatively set to unity in the PQRAs. In Equation 5-2, the contaminant concentration in topsoil was used for the American kestrel and the maximum of topsoil and surface soil concentrations for the masked shrew. Refer to Figure 5-5 for the respective dose calculation influence diagrams.

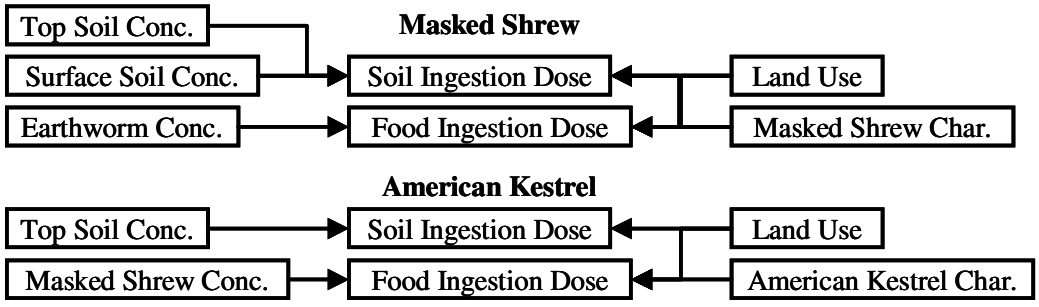

Figure 5-5 Influence diagram for masked shrew and American kestrel dose calcs.

Water and sediment contact doses, having units of mg/L and mg/kg, respectively, for aquatic life were the measured concentrations in water and sediment, respectively.

5.2.2.4 Biotransfer Equations

Contaminant concentrations in plants, produce, earthworms, masked shrew, beef, and milk (i.e., receptor food sources) were calculated using equations from or based on CCME (2006). For plants and produce, contaminant concentrations were estimated using Equation 3-3, which was derived to accommodate bioaccumulation data expressed in the source documents as either a biotransfer factor, B_p, or as a regression equation expressed in the form $\ln(C_p) = k_2 \ln(C_s) + k_3$:

Equation 5-3 $$C_p = k_1 \exp[k_2 \ln(C_s) + k_3]$$

where:

- C_p = contaminant concentration in dry produce or plants (mg/kg_{dw});
- C_s = contaminant concentration in soil (mg/kg); and,
- k_1, k_2, and k_3 = contaminant specific bioaccumulation constants.

In cases where bioaccumulation data was not available for a contaminant, k_1 was set to zero meaning the contaminant was assumed not to bioaccumulate. The maximum contaminant concentration in topsoil and surface soil was used in the calculation.

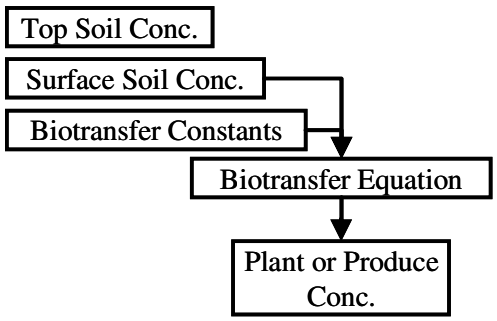

Figure 5-6 Influence diagram for calculated plant and produce concentrations

Similarly, biotransfer factors were also required to estimate the concentrations of contaminants in food consumed by masked shrew and American kestrel. The equation above was used to estimate contaminant concentrations in the assumed primary food source for these two consumers: earthworms and masked shrew, respectively:

Equation 5-4 $$C_{worm} \; or \; C_{shrew} = k_4 \exp[k_5 \ln(C_s) + k_6]$$

where:

- C_{worm}, C_{shrew} = contaminant concentration in earthworms and masked shrew (mg/kg_{dw}); and,
- k_4, k_5, k_6 = contaminant specific bioaccumulation constants.

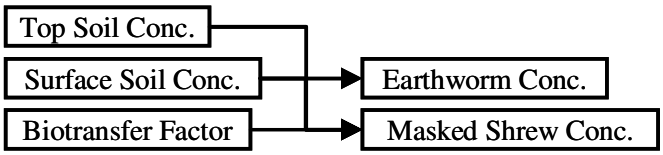

Figure 5-7 Influence diagram for calculated earthworm and masked shrew concentrations

Potential contaminant concentrations in beef and milk were calculated using the equations above recommended by CCME (2006):

Equation 5-5 $$C_b = B_b \times C_s \times IR_s$$

Equation 5-6 $$C_m = B_m \times C_s \times IR_s$$

where:

- C_b, C_m = contaminant concentration in beef and milk, respectively (mg/kg); and,
- B_b, B_m = biotransfer factor for beef and milk, respectively (d/kg).

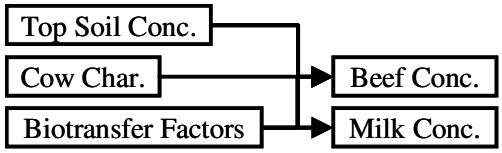

Figure 5-8 Influence diagram for calculated beef and milk concentrations

5.2.2.5 Contaminant Transport Equations

The contaminant transport models and assumptions recommended by CCME (2006) were used as a basis in predicting the transport of contaminants via groundwater, vapour, wind, and surface water runoff. These models are simplifications of actual transport process but are appropriate given the limited information typically available for most contaminated sites.

5.2.2.5.1 Vapour Transport

At each cell, the estimated soil vapour concentrations in impacted surface soil and in subsoil, $C_{a,soil}$, were calculated using the following partitioning equation (CCME 2006):

Equation 5-7 $$C_{a,soil} = C_t H' \rho_b / (\theta_w + K_d \rho_b + H' \theta_a)$$

where:

- C_t = total concentration of contaminant in soil (mg/kg);
- ρ_b = soil bulk density in vadose zone (g/cm^3);
- θ_a = air filled porosity (-); and,
- θ_w = water filled porosity (-).

The vapour concentration immediately above impacted groundwater, $C_{a,gw}$, was calculated using $C_{a,gw} = C_w H'$. The ideal gas law equation was used to determine the

maximum vapour concentration from impacted soil or groundwater. A temperature of 294 K was used based on measured soil temperatures beneath buildings (CCME 2008a).

At each cell, the maximum of vapour concentrations in impacted surface soil and subsoil and above impacted groundwater, C_a, was compared to $C_{a,max}$, the contaminant's vapour pressure. If C_a exceeded $C_{a,max}$, then C_a was set equal to $C_{a,max}$. The resultant C_a value was used in subsequent vapour transport calculations.

If a cell had a vapour concentration greater than zero and at least one habitable building was present, a soil vapour attenuation factor, α_{vap}, was determined to predict the indoor vapour concentration, $C_{a,indoor}$. If the distance between the contaminant source and the building foundation was less than 0.30 m, α_{vap} was set to 0.01 as per guidance from AENV (2009b). Otherwise, the Johnson & Ettinger (1991) equation as presented by AENV (2009b) was used to calculate α_{vap}. The indoor vapour concentration was estimated by multiplying the vapour concentration by the vapour attenuation factor: $C_{a,indoor} = C_a \alpha_{vap}$. Figure 5-9 summarises the inputs needed to calculate indoor vapour concentrations.

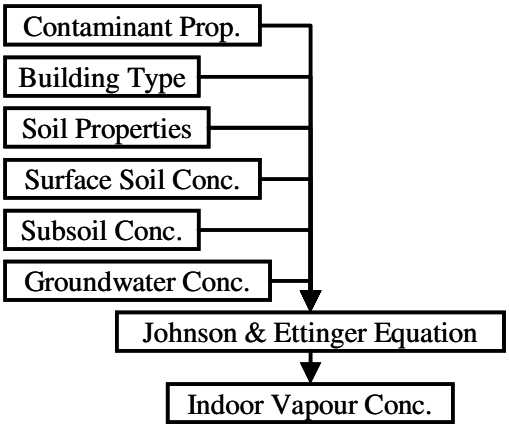

Figure 5-9 Influence diagram for calculated indoor vapour concentrations

5.2.2.5.2 Particulate Transport

Health Canada (2004a) recommends using an estimated annual average particulate concentration of 0.76 mg/m^3 above a contaminated site when conducting risk assessments. The basis of this value is the following "unlimited reservoir" Equation 5-8 developed by Cowherd *et al*. (1985) as presented by the USEPA (1996, 2002) using default input parameters used by the USEPA (*ibid*):

Equation 5-8 $$C_{pm} = 10^{-5}\left(C_{wind}/Q_{pm}\right)(1-V)\left(U_m/U_t\right)^3 F(x)$$

where:

- C_{pm} = average particulate concentration in ambient air (kg/m^3);
- C_{wind}/Q_{pm} = normalised annual average particulate concentration (0.01101 kg/m^3 per g/m^2·s);
- V = fraction of surface covered by vegetation (0.5);
- U_m = mean annual wind speed (4.69 m/s);
- U_t = equivalent erosion threshold wind speed at 7 m above surface (11.32 m/s); and,
- $F(x)$ = function dependent on U_m/U_t (0.194).

The default vegetation cover fraction, V, of 0.5 implies that on a per square metre basis half of the contaminated site surface is covered by vegetation that restricts wind scour and particulate matter entrainment. For the PQRAs, V was considered a variable and assigned a value of zero for a completely vegetated site or site with a non-erodible surface (e.g. asphalt), 0.5 for a partially vegetated site, and 1.0 for a site dominated by bare soil.

At each cell, the particulate contaminant concentration, C_{part}, was calculated using the equation $C_{part} = C_{ts} \times C_{pm}$ where C_{ts} is the contaminant concentration in topsoil (mg/kg).

5.2.2.5.3 Groundwater Transport

CCME (2006) considers four processes in the transport of soil contaminants to groundwater: soil leachate generation, vadose zone transport, groundwater mixing, and groundwater transport. At each cell and soil stratum, soil leachate concentration, C_l, was estimated using the following logic: If the measured contaminant concentration in soil, C_s, was less than the soil concentration in equilibrium with the contaminant's effective solubility, $C_{s,max}$, then $C_l = C_s / K_d$; otherwise the leachate concentration was set to the effective solubility, S_e, where $S_e = XS$, $C_{s,\max} = S_e K_d$, and:

- K_d = distribution coefficient (mL/g);
- S = pure phase solubility of contaminant (mg/L); and,
- X = mole fraction of contaminant in a mixture, conservatively set to unity.

The maximum calculated leachate concentration in topsoil, surface soil, and subsoil was then used in subsequent calculations.

Vadose zone contaminant transport is influenced by precipitation infiltration rates. AENV (2009a) concludes that groundwater recharge by infiltration is less than 10% of precipitation through coarse grained soils and less than 2% through fine grained soils based on a significant amount of research conducted by others for the Prairies provinces. These percentages were also used here at contaminated sites outside of the Prairies.

At each cell, if the soil surface had an impermeable cover, such as asphalt, the assumed precipitation infiltration rate, *I*, was zero. However, if the surface was permeable and the vadose zone soil was coarse grained, as defined by CCME (2006), infiltration rate was calculated as 10% of the average annual precipitation for the contaminated site. The average annual precipitation was based on historical climate normals published by Environment Canada (2010). If the vadose zone was fine grained, the infiltration rate was calculated as 2% of average annual precipitation.

The attenuation coefficient, α_{us}, for a contaminant as it migrates through the vadose zone was calculated using the series of equations based on CCME (2006) and published by AENV (2009b). The attenuated leachate concentration before mixing with unimpacted groundwater, $C_{l,gw,i}$, was calculated using $C_{l,gw,i} = C_l \times \alpha_{us}$. The area weighted average, as calculated using Equation 5-9, of all $C_{l,gw,i}$ values beneath a contaminant source zone was used for the subsequent groundwater transport calculations.

Equation 5-9

$$C_{l,gw,ave} = \sum_{i=0}^{n} w_i C_{l,gw,i} \Big/ \sum_{i=0}^{n} w_i$$

where:

- wi = distance interval between a cell's upper and lower bound along a given direction (m); and,
- $C_{l,gw,i}$ = leachate concentration in groundwater within a cell before mixing with unimpacted groundwater (mg/L).

For simplicity, the groundwater mixing factor was conservatively set to unity.

As leachate percolates through the vadose zone, contaminant can partition onto the surface of soil particles according to the following equation: $C_s = C_{l,gw,ave} \times K_d$. At

each cell for each soil stratum, if the predicted contaminant concentration adsorbed to soil was greater than the measured value, the concentration was updated with the predicted value.

The two dimensional, steady state form of the groundwater contaminant transport equation published by AENV (2009b), which is based on CCME (2006), was used in estimating a groundwater contaminant attenuation factor, α_{gw}, down gradient of a source. A limitation of this equation is it cannot be used if the distance between source and receptor is less than 10 m, in which case α_{gw} was set to unity. At each cell, if the predicted groundwater concentration was less than the measured value, the measured groundwater concentration was used.

Similar to the discussion regarding leachate adsorbing onto soil surfaces in the vadose zone, if the predicted contaminant concentration adsorbed to soil was greater than the measured value, the concentration was updated with the predicted value.

5.2.2.5.4 Water and Wind Transport

The extent of contaminant transport via water or wind was assumed to be twice the distance from the centre of topsoil contamination to the edge of topsoil contamination in all directions. The assumed contaminant concentration in receiving soils was one half the weighted average of concentrations in the contaminated topsoil source zone.

5.2.3 Toxicity Assessment

Health Canada (2004b, 2006b), CCME (2008a,b, 2009), and AENV (2009a) were the Canadian sources for human toxicity data and USEPA (2009c) and ORNL (2009) were the sources from the United States. Ecological receptor toxicity information was obtained from CCME (2008b, 2009), AENV (2009a), and USEPA (2009b).

5.2.4 Risk Characterization

5.2.4.1 Hazard Quotients

At each cell, the hazard posed by each contaminant, to each receptor, via each exposure route was expressed as a dimensionless hazard quotient, $HQ_{i,j,k,m}$, which is the measured or predicted dose divided by the tolerable dose (Suter 2007). For human and terrestrial animal receptors, $HQ_{i,j,k,m}$ was expressed as predicted daily intake, *PDI*, divided by tolerable daily intake, *TDI*. For terrestrial plants, soil invertebrates, and microorganisms, the ratio of measured or predicted soil concentration, *PSoC*, to tolerable soil concentration, *TSoC*, defined $HQ_{i,j,k,m}$. For aquatic plants and animals, $HQ_{i,j,k,m}$ was expressed as measured or predicted water concentration, *PWC*, and sediment concentration, *PSdC*, divided by tolerable water, *TWC*, and sediment concentration, *TSdC*, respectively.

The hazard quotient approach is appropriate where the dose vs. effect curve for a contaminant is not available or required (Suter 2007), as is the case with the PQRAs. Typically, hazard quotients are used to characterise the hazards associated with threshold effect contaminants (i.e. non-carcinogens) and risk values (e.g. 10^{-4} probability) used to describe non-threshold effect contaminants (HC 2004a). However, to permit combining hazards due to both carcinogenic and non-carcinogenic contaminants, the hazards associated with carcinogenic contaminants were also expressed as hazard quotients. A limitation of this simplification is carcinogenic risk values are not explicit in the calculation. If necessary, risk values can be back calculated by multiplying the carcinogenic $HQ_{i,j,k,m}$ by the acceptable risk level of 10^{-5} (HC 2004a). A hazard quotient does not convey a likelihood or probability of an adverse effect upon a biological

receptor, but is a measure of the potential for adverse effect where a higher *HQ* means a higher adverse effect potential without quantifying that potential in an absolute sense.

5.2.4.2 Hazard Indices and Cumulative Hazard Indices

Similar to the approach proposed by USEPA (2005), hazard quotients were combined across contaminants to obtain a hazard index, $HI_{i,k,m}$, for a given receptor and exposure route at each cell. Then, $HI_{i,k,m}$, values were combined across exposure routes for a given receptor to obtain a cumulative hazard index, $CI_{i,k}$, for each receptor at each cell. Finally, the maximum $CI_{i,k}$ value for each receptor was used to characterise receptor hazard, CI_k.

Equation 5-10

$$CI_k = \max\left(\sum_{m=1}^{d}\sum_{j=1}^{b} HQ_{i,j,k,m}\right)_{i=1}^{a}$$

where: i = cell "i"; j = contaminant "j"; k = receptor "k"; and, m = exposure route "m".

5.2.4.3 Combining Cumulative Hazard Indices for Ecological Receptors

Quantifying the overall hazard of a contaminated site to all 7 ecological receptors or receptor groups is confounded by the absence of a generally accepted protocol. Since cumulative hazard indices are normalised values based on tolerable doses or concentrations, a practical solution is to simply declare that a central tendency measure of CI_k values be used as estimators to characterise the set of 7 ecological receptor CI_k values for a contaminated site. Given that CI_k values can range over many orders of magnitude, the geometric mean was chosen, $aveCI_{eco}$. In cases where a particular receptor had CI_k equal to zero, CI_k was set to a small number (i.e., 10^{-4}) that would not have a significant influence on the final result yet allow calculation of the geometric mean.

5.2.5 Scenarios

Two exposure scenarios were evaluated in the PQRAs: known and potential. In the known scenario, $knCI_k$ values were calculated for the existing combination of contaminant concentrations and their locations, current exposure routes, and land uses as supported by the ESA reports for a contaminated site. In the potential scenario, $poCI_k$ values were calculated for the potential contaminant concentrations after applying the contaminant transport models described previously and incorporating potential exposure routes within the defined land uses.

5.2.6 Contaminated Site Selection

The Federal Contaminated Site Inventory (FCSI) was used to search for a collection of contaminated sites (TBCS 2005) based on three criteria:

- the sites should represent the more frequently encountered contaminant types;
- the sites should represent the varied climate and geography across Canada; and,
- at minimum, a Phase II ESA must have been completed at each site.

Figure 5-10 ranks contaminant types according to the number of contaminated sites in the FCSI having soil impacts of each type. The number of sites with groundwater, surface water, and sediment impacts are also shown. Focusing on soil, Figure 5-10 indicates that almost 90% of contaminated sites have soil impacted by metals; petroleum hydrocarbons (PHCs) including benzene, toluene, ethylbenzene, xylenes (BTEX); and polycyclic aromatic hydrocarbons (PAHs). Thus, the selected sites focused on these contaminants.

Sites were chosen from the Northwest Territories, Nunavut, and Yukon to represent Canada's North; sites in British Columbia and the Alberta Foothills to represent the West Coast and Rocky Mountains; sites in Saskatchewan and Manitoba, for the

Prairies; sites in Ontario for Central Canada; and sites in the Atlantic Provinces for the Canadian Maritimes. To meet the third criterion, sites were selected from those that meet *Step 6 – Detailed Testing Program* of the Federal 10 Step Process (CSMWG 1999). Using these criteria, 20 sites were selected from the FCSI and contaminated site information requested via the federal *Access to Information Act* (GoC 1985).

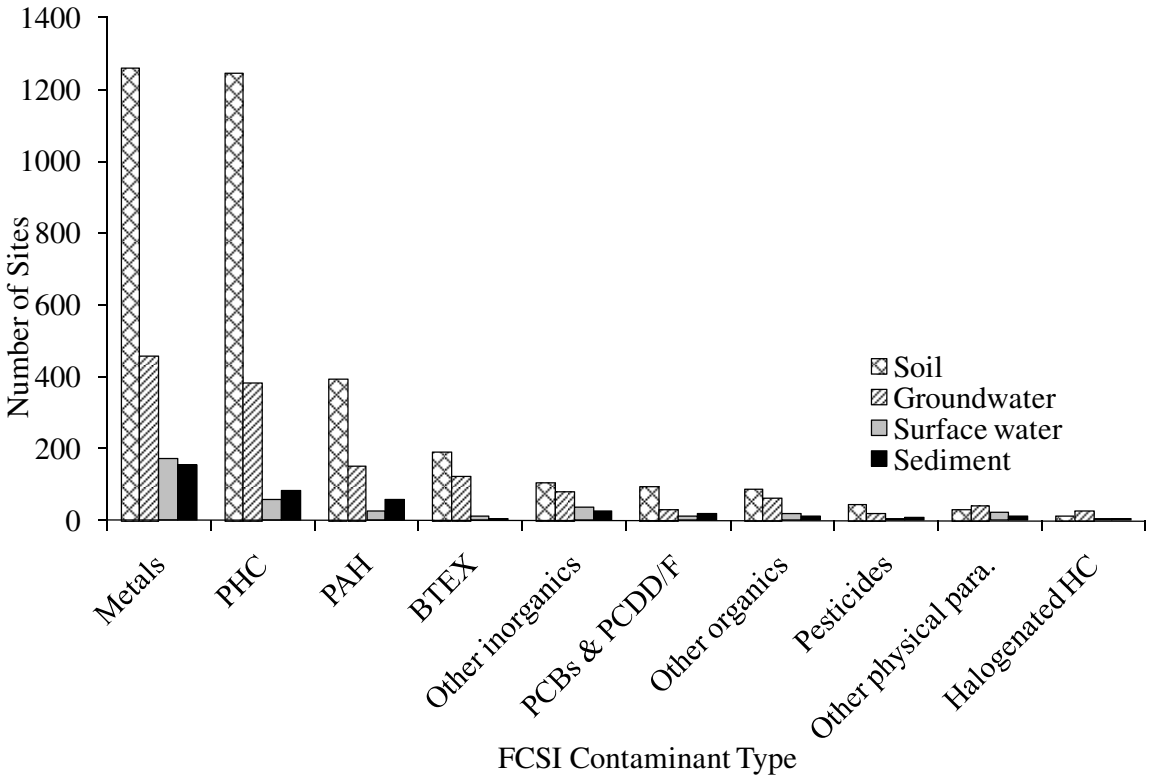

Figure 5-10 Pareto diagram of contaminant types in FCSI (TBCS 2005)

Table 5-4 briefly summarises information on the selected contaminated sites obtained from ESA reports. Ecoregions are as defined by NRCan (2009). The reports are publicly available and were prepared by the following entities: AMEC (2004a,b, 2005, 2008); Azimuth, Golder, and SNC (2007, 2008); Bryant (2003); EMS (2004a,b); Franz (2005, 2006); Golder (2001); Hemmera (2001, 2002); JWAL (1991, 1993); JWEL (1998, 2002); JWL (2004, 2006); JASA (2007); KGS (2002, 2003a,b); Meridian (2006,

2007a,b); NRCC (2007, 2008); OMM (1997, 1998, 1999); Parks Canada (2007); PGL (2002, 2006); RMC (2001); SEACOR (2006a,b); SNC (2007, 2008a,b); Teranis (2007a,b); UMA (2008); and Wardrop (1997).

Table 5-4 Selected contaminated sites

Site Id	Contaminant Source	Province or Territory	Ecoregion	Contaminant Types
1	Waste soil landfill	BC	Eastern Vancouver Island	Metals, PCBs, PAHs, PHCs
2	Above ground storage tank	BC	Western Vancouver Island	PAHs, PHCs
3	Weathered paint	ON	Manitoulin-Lake Simcoe	Metals
4	Mechanical repair area	BC	Coastal Gap	Metals, PAHs, PHCs
5	Above ground storage tank	YT	Ruby Ranges	PAHs, PHCs
6	Waste dump	BC	Eastern Vancouver Island	Metals, PAHs, PCBs, PHCs
7	Soak away pit	ON	St. Laurent Lowlands	Chlorinated solvents
8	Salt storage area	AB	Northern Continental Divide	Salts
9	Underground storage tank	PE	Prince Edward Island	Metals, PAHs, PHCs
10	Spilled fuel	NB	Maritime Lowlands	Metals, PAHs, PHCs
11	Chemical dump	ON	St. Laurent Lowlands	Chlor. solvents, Metals, PHCs
12	Underground storage tank	ON	Thunder Bay-Quetico	PHCs
13	Above ground storage tank	MB	Aspen Parkland	PHCs
14	Underground storage tank	SK	Aspen Parkland	PHCs
15	Wastewater lagoon	SK	Aspen Parkland	PHCs
16	Pesticide dump	SK	Aspen Parkland	Metals, Phenols
17	Equipment dump	NU	Eureka Hills	Metals
18	Above ground storage tank	NT	Tazin Lake Upland	PHCs
19	Waste dump	AB	Fescue Grassland	DDT, Metals, PAHs
20	Above ground storage tank nest	NT	Tuktoyaktuk Coastal Plain	PHCs

5.3 Results & Discussion

5.3.1 Known Scenario

Figure 5-11 to Figure 5-17 are a series of log-log plots relating the cumulative hazard indices for each of the 7 ecological receptors to human receptor cumulative hazard indices, $knCI_{human}$, under the known scenario. Figure 5-18 relates the geometric mean of ecological receptor cumulative hazard indices, $kn,aveCI_{eco}$, to $knCI_{human}$ under the same scenario. Common to all plots are several outliers positioned along either the vertical or horizontal axes where $knCI_k$ is negligible (i.e., $\leq 10^{-4}$). Investigation of the reasons for these outliers indicates that if a receptor is not present under a land use, as defined in Table 5-1; or if all contaminant exposure routes for a receptor, as defined in Table 5-2, are not present; or if there are no defined tolerable doses for the set of chemicals to which a receptor is exposed; then the cumulative hazard index for a receptor is zero. These outliers illustrate the environmental risk assessment concept that a contaminant source, exposure route, and receptor must all be present for a risk to exist.

Excluding these outliers, the remaining data were examined to assess whether acceptable correlations exist. Referring to Figure 5-13 and Figure 5-16, a strong positive and linear correlation exists for cow and kestrel cumulative hazard indices, $knCI_{cow}$ and $knCI_{kestrel}$, when compared to $knCI_{human}$. This observation is supported by the associated Student *t* statistics which satisfy a maximum Type I error probability, α, of 5%. The same statistical analysis was conducted on the remaining plots to verify correlation observations. A summary of this analysis is provided in Table 5-5. Figures having a dashed linear regression line indicate the correlation is not acceptable at the defined α value. Referring to Figure 5-12, the correlation between soil microorganisms cumulative

hazard indices, $knCI_{micro}$, and $knCI_{human}$ is not satisfactory; however, acceptable correlations exist between the remaining ecological receptors' indices and $knCI_{human}$.

Table 5-5 $knCI_k$ vs. $knCI_{human}$ correlation statistics

$knCI_k$	r_p	n	t	t_a	Correlation acceptable?
$knCI_{human}$	-	-	-	-	-
$knCI_{plant}$	0.67	14	3.13	1.78	Yes
$knCI_{micro}$	0.49	9	1.50	1.89	No
$knCI_{cow}$	1.00	4	16.8	2.92	Yes
$knCI_{vole}$	0.92	6	4.83	2.13	Yes
$knCI_{shrew}$	0.89	6	3.95	2.13	Yes
$knCI_{kestrel}$	0.99	4	9.90	2.92	Yes
$knCI_{aquatic}$	0.91	4	3.04	2.92	Yes
$kn,aveCI_{eco}$	0.75	14	3.98	1.78	Yes

Where acceptable correlations exist, the following regression equations provide an approximate relationship between some ecological receptors $knCI_k$ values and $knCI_{human}$. The range of $knCI_{human}$ values within which the equations are valid are also specified. The equations represent a band of probable ecological receptor *CI* results having 90% prediction intervals ranging from approximately 1 to 4 orders of magnitude with the exception of Equation 5-12 (cow) and Equation 5-15 (kestrel), which almost match the data precisely. The relationship between $kn,aveCI_{eco}$, and $knCI_{human}$ is the least precise of the set.

Equation 5-11 $\log(knCI_{plant}) = [0.43\log(knCI_{human}) + 0.92] \pm 1; \quad 0.03 < knCI_{human} < 3{,}000$

Equation 5-12 $\log(knCI_{cow}) = [0.76\log(knCI_{human}) - 1.4]; \quad 3 < knCI_{human} < 3{,}000$

Equation 5-13 $\log(knCI_{vole}) = [0.81\log(knCI_{human}) - 0.91] \pm 0.5; \quad 3 < knCI_{human} < 3{,}000$

Equation 5-14 $\log(knCI_{shrew}) = [1.3\log(knCI_{human}) - 1.2] \pm 1; \quad 3 < knCI_{human} < 3{,}000$

Equation 5-15 $\log(knCI_{kestrel}) = [0.71\log(knCI_{human}) - 0.92]; \quad 30 < knCI_{human} < 3{,}000$

Equation 5-16 $\log(knCI_{aquatic}) = [1.0\log(knCI_{human}) - 0.14] \pm 1; \quad 0.3 < knCI_{human} < 3{,}000$

Equation 5-17 $\log(kn, aveCI_{eco}) = [0.94\log(knCI_{human}) - 2.6] \pm 2; 0.03 < knCI_{human} < 3{,}000$

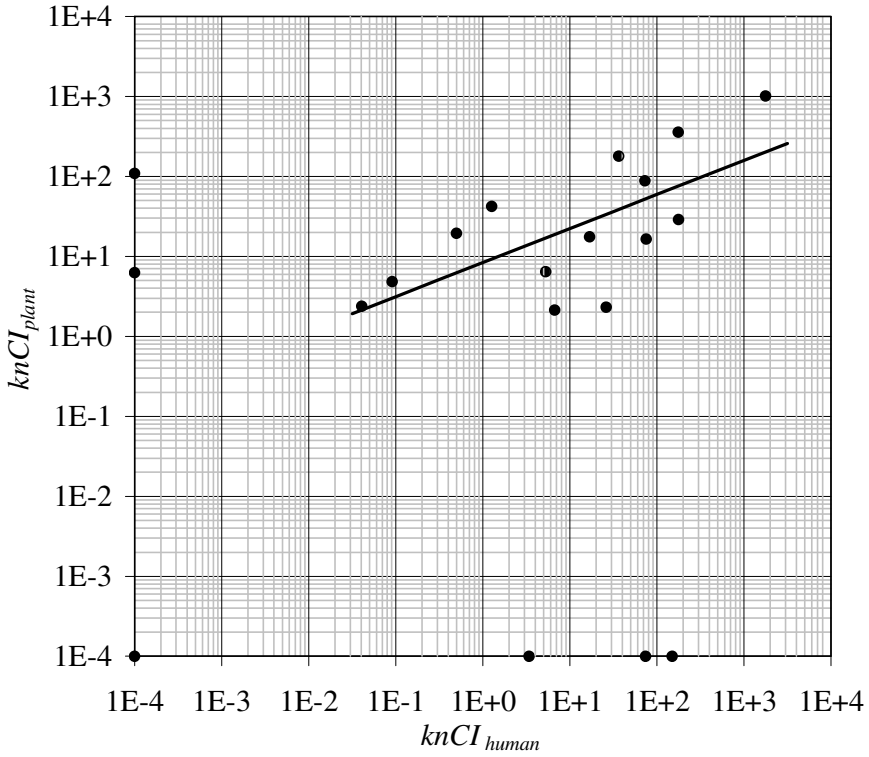

Figure 5-11 *knCI*$_{plant}$ vs. *knCI*$_{human}$

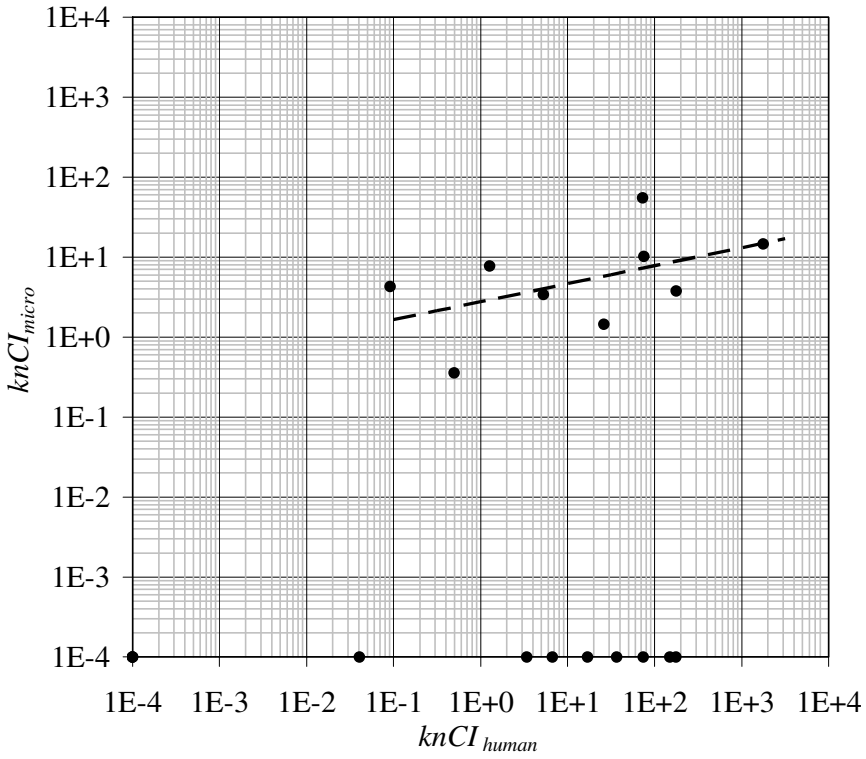

Figure 5-12 *knCI*$_{micro}$ vs. *knCI*$_{human}$

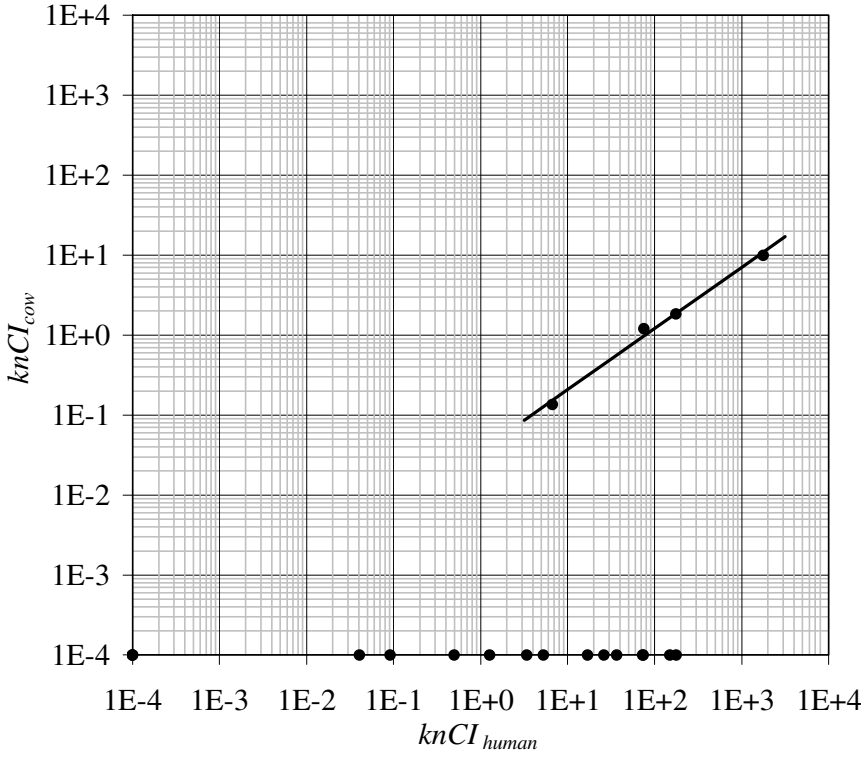

Figure 5-13 *knCI*$_{cow}$ vs. *knCI*$_{human}$

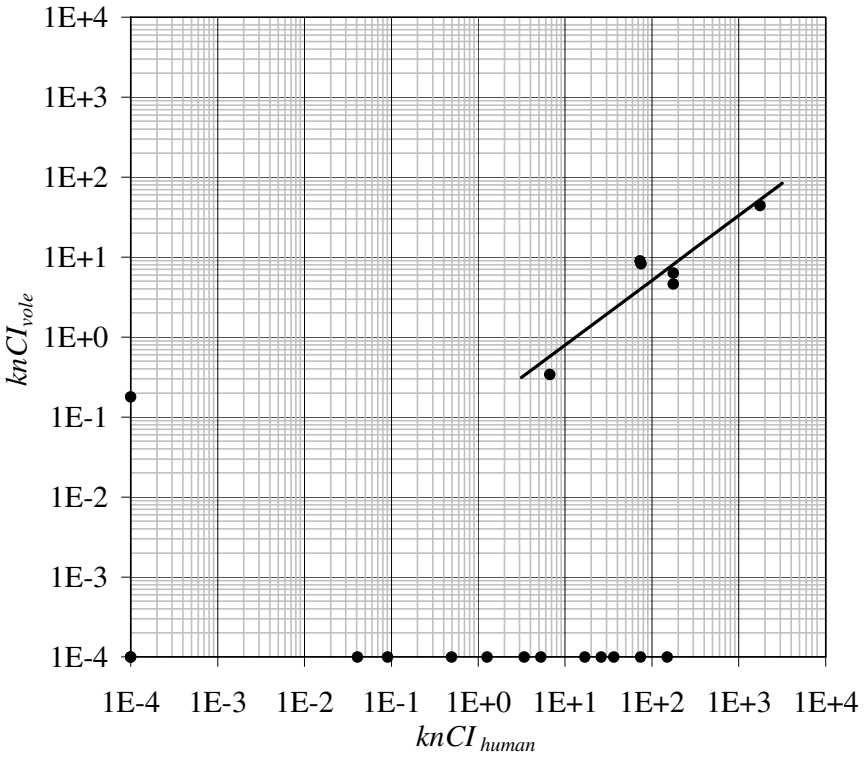

Figure 5-14 *knCI*$_{vole}$ vs. *knCI*$_{human}$

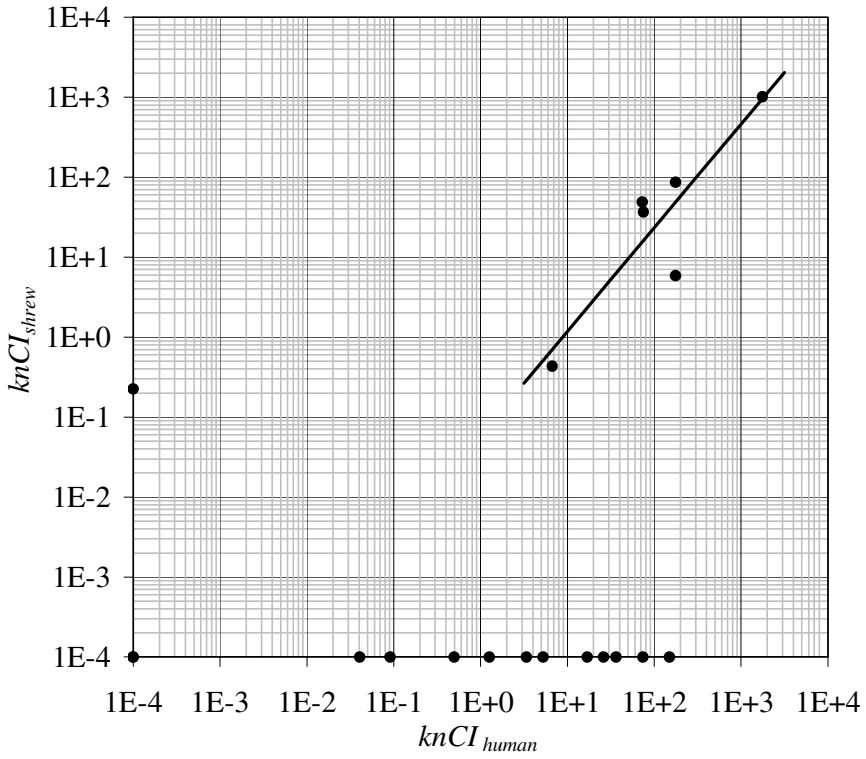

Figure 5-15 *knCI*$_{shrew}$ vs. *knCI*$_{human}$

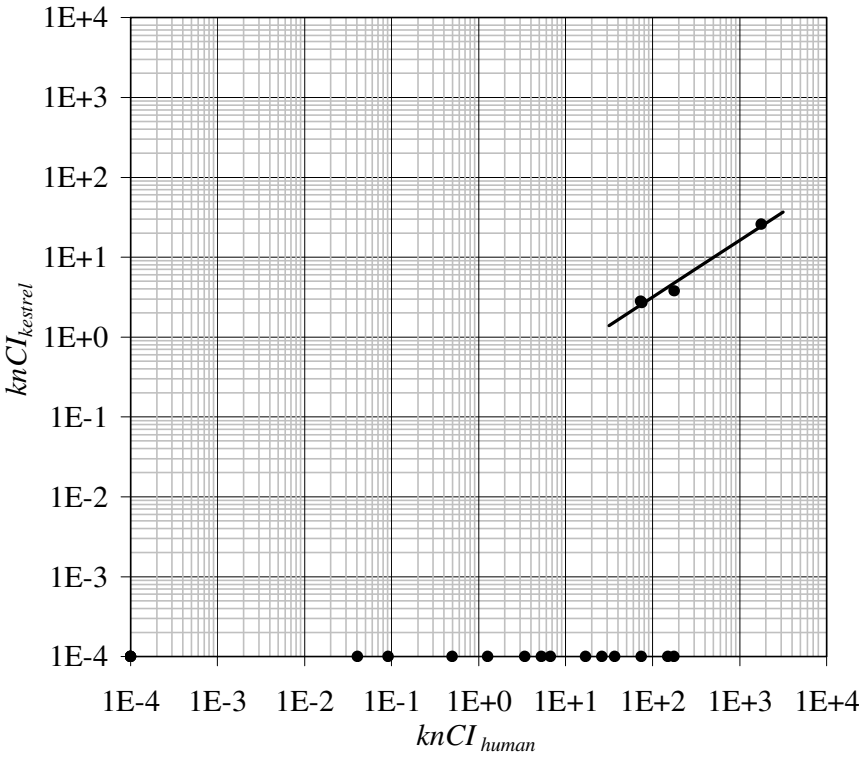

Figure 5-16 *knCI*$_{kestrel}$ vs. *knCI*$_{human}$

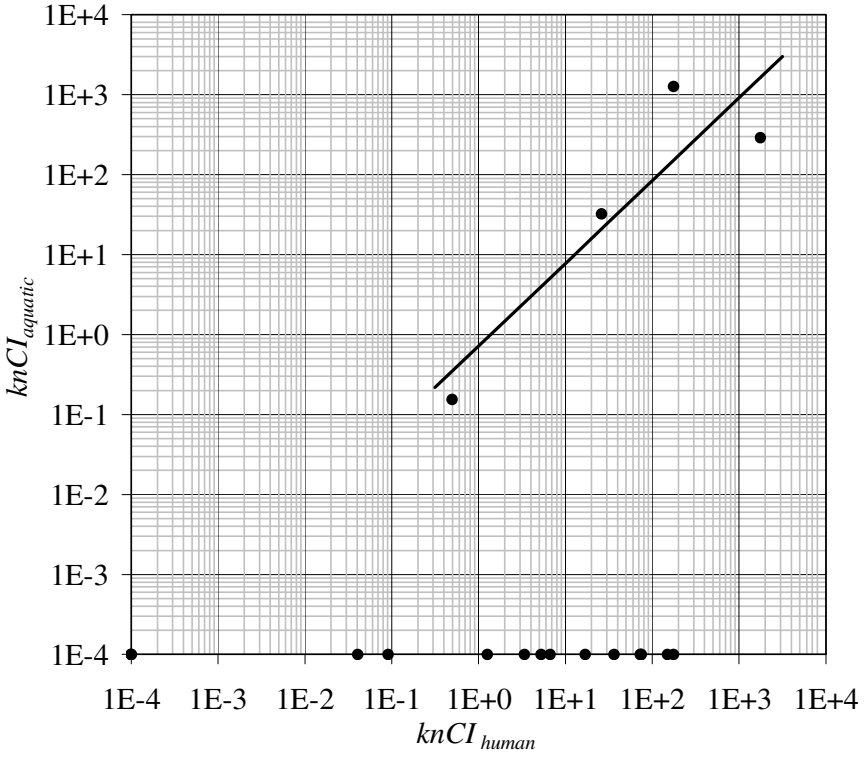

Figure 5-17 *knCI*$_{aquatic}$ vs. *knCI*$_{human}$

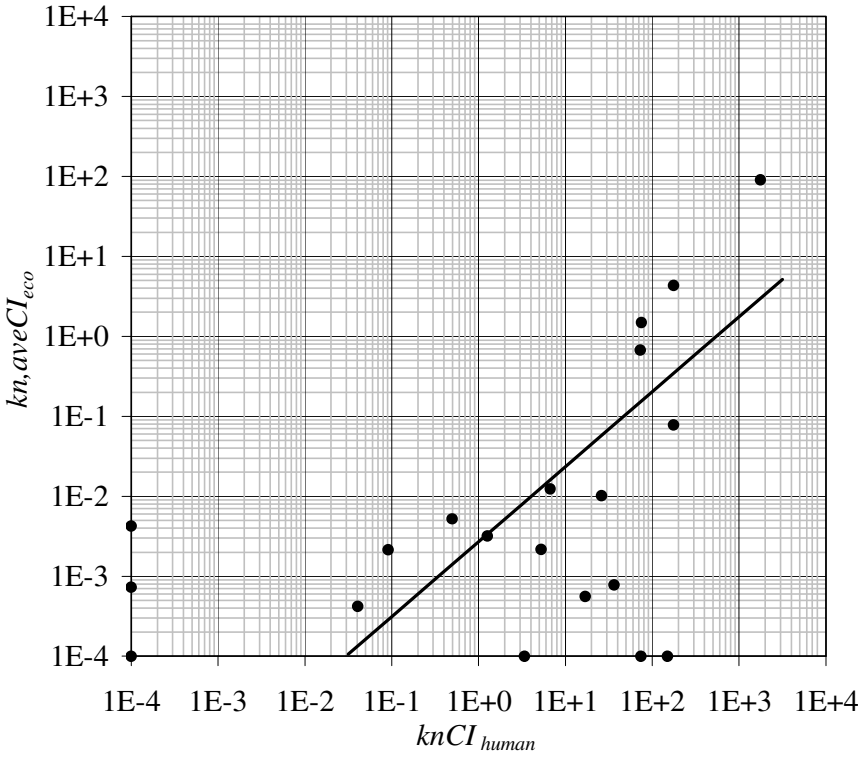

Figure 5-18 *kn,aveCI*$_{eco}$ vs. *knCI*$_{human}$

Of all the ecological receptors or receptor groups investigated, plants & soil invertebrates have the greatest number of CI_k values greater than 10^{-4} and were investigated to assess whether this receptor group can act as a surrogate for the other ecological receptors. Figure 5-19 to Figure 5-25 are a series of log-log plots relating ecological receptor cumulative hazard indices to plant & invertebrate cumulative hazard indices, $knCI_{plant}$, under the known scenario. The reasons for the outliers and the process of establishing acceptable correlation are the same as stated before. Again, the strongest correlations exist for cow and kestrel cumulative hazard indices, $knCI_{cow}$ and $knCI_{kestrel}$. The weakest are for soil microorganisms and aquatic life, $knCI_{micro}$ and $knCI_{aquatic}$. The strong correlation with cows is reasonable given a cow's herbivore diet and the weak correlation with aquatic life understandable since terrestrial and aquatic ecosystems do

not overlap in the PQRAs. The following regression equations relate ecological receptors $knCI_k$ values with $knCI_{plant}$. The equations represent a band of probable results having widths ranging from 1 to 5 orders of magnitude. Again, the relationship between $kn,aveCI_{eco}$ and $knCI_{plant}$ is the least precise of the set.

Equation 5-18 $\log(knCI_{cow}) = \lfloor 0.58\log(knCI_{plant}) - 0.92 \rfloor \pm 0.5; \quad 1 < knCI_{human} < 1{,}000$

Equation 5-19 $\log(knCI_{vole}) = \lfloor 0.73\log(knCI_{plant}) - 0.64 \rfloor \pm 1; \quad 1 < knCI_{human} < 1{,}000$

Equation 5-20 $\log(knCI_{shrew}) = \lfloor 1.0\log(knCI_{plant}) - 0.51 \rfloor \pm 1.5; \quad 1 < knCI_{human} < 1{,}000$

Equation 5-21 $\log(knCI_{kestrel}) = \lfloor 0.54\log(knCI_{plant}) - 0.30 \rfloor \pm 0.5; \quad 10 < knCI_{human} < 1{,}000$

Equation 5-22 $\log(kn, aveCI_{eco}) = \lfloor 0.52\log(knCI_{plant}) + 0.77 \rfloor \pm 2.5; \; 1 < knCI_{human} < 1{,}000$

Table 5-6 is a summary of the associated statistical analysis regarding the correlation.

Table 5-6 $knCI_k$ vs. $knCI_{plant}$ correlation statistics

$knCI_k$	r_p	n	t	t_a	Correlation acceptable?
$knCI_{human}$	0.67	14	3.13	1.78	Yes
$knCI_{plant}$	-	-	-	-	-
$knCI_{micro}$	0.55	9	1.73	1.89	No
$knCI_{cow}$	0.93	4	3.71	2.92	Yes
$knCI_{vole}$	0.82	7	3.18	2.02	Yes
$knCI_{shrew}$	0.74	7	2.48	2.02	Yes
$knCI_{kestrel}$	0.91	4	3.11	2.92	Yes
$knCI_{aquatic}$	0.33	4	0.49	2.92	No
$kn,aveCI_{eco}$	0.47	16	1.99	1.76	Yes

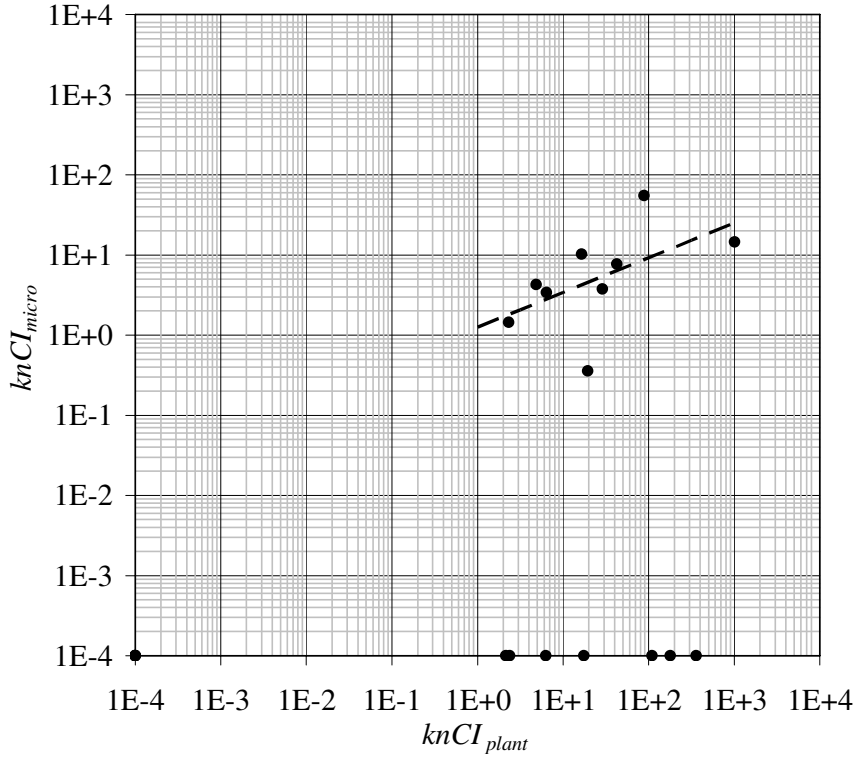

Figure 5-19 $knCI_{micro}$ vs. $knCI_{plant}$

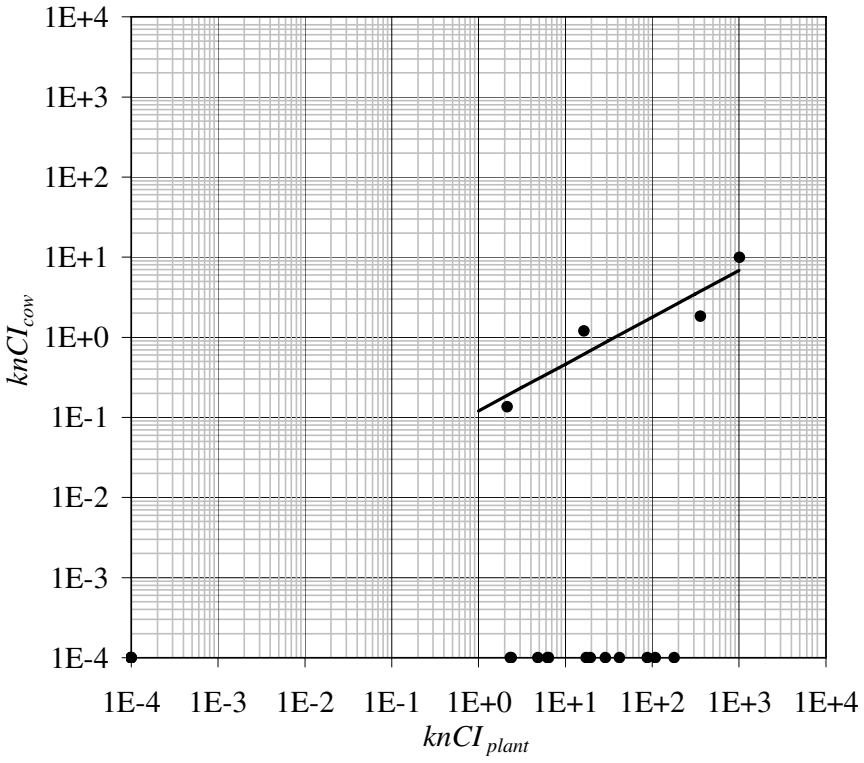

Figure 5-20 $knCI_{cow}$ vs. $knCI_{plant}$

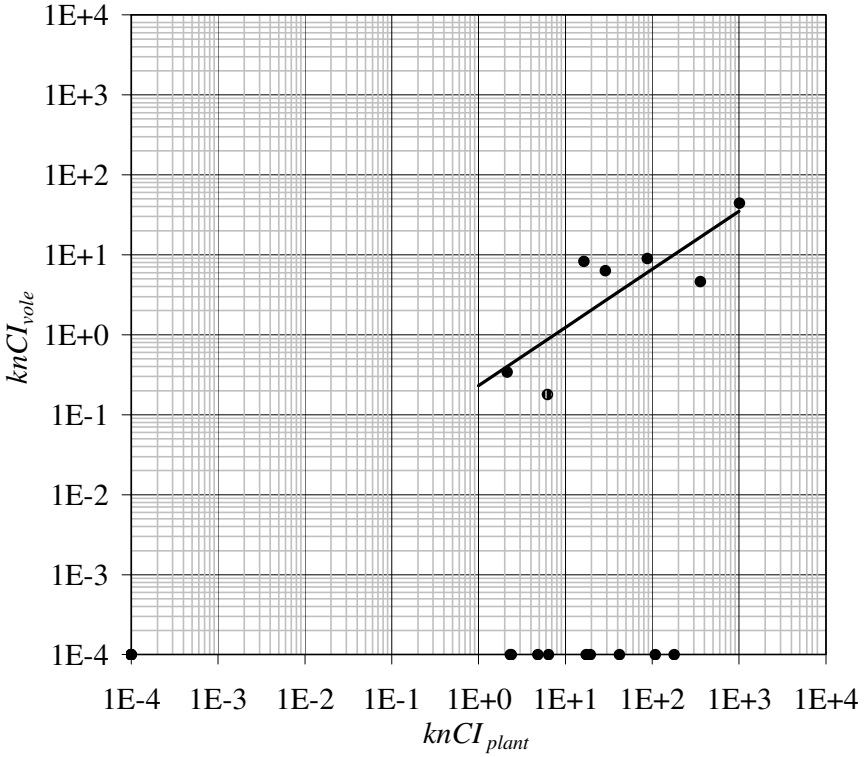

Figure 5-21 *knCI*$_{vole}$ vs. *knCI*$_{plant}$

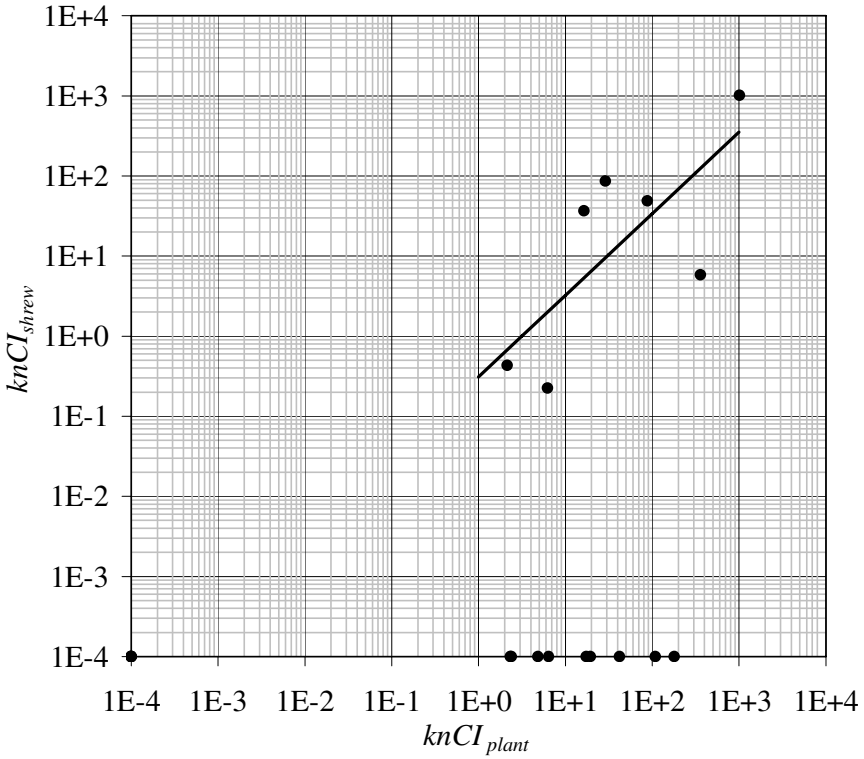

Figure 5-22 *knCI*$_{shrew}$ vs. *knCI*$_{plant}$

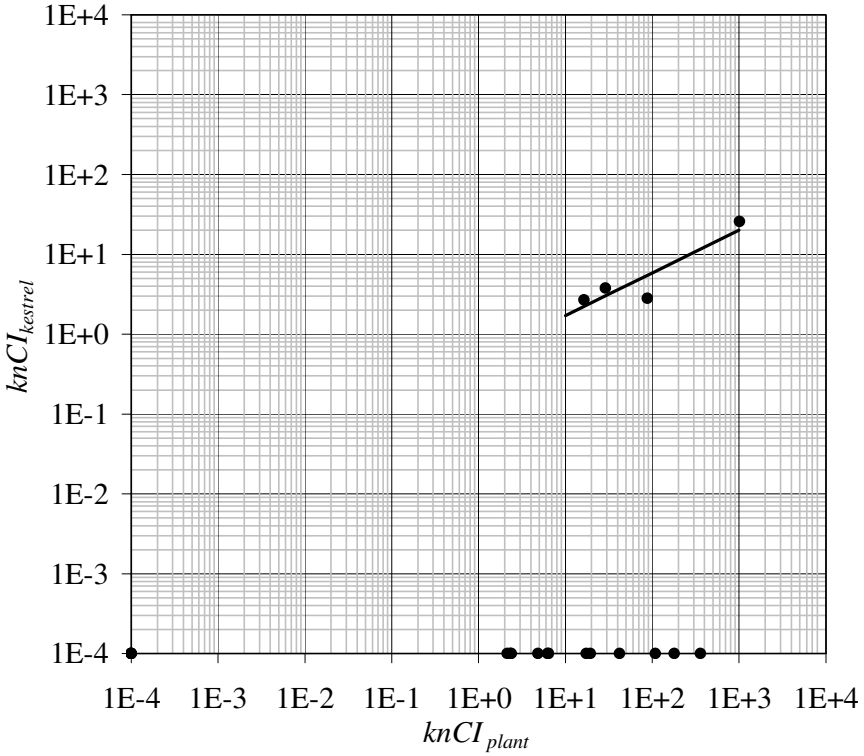

Figure 5-23 $knCI_{kestrel}$ vs. $knCI_{plant}$

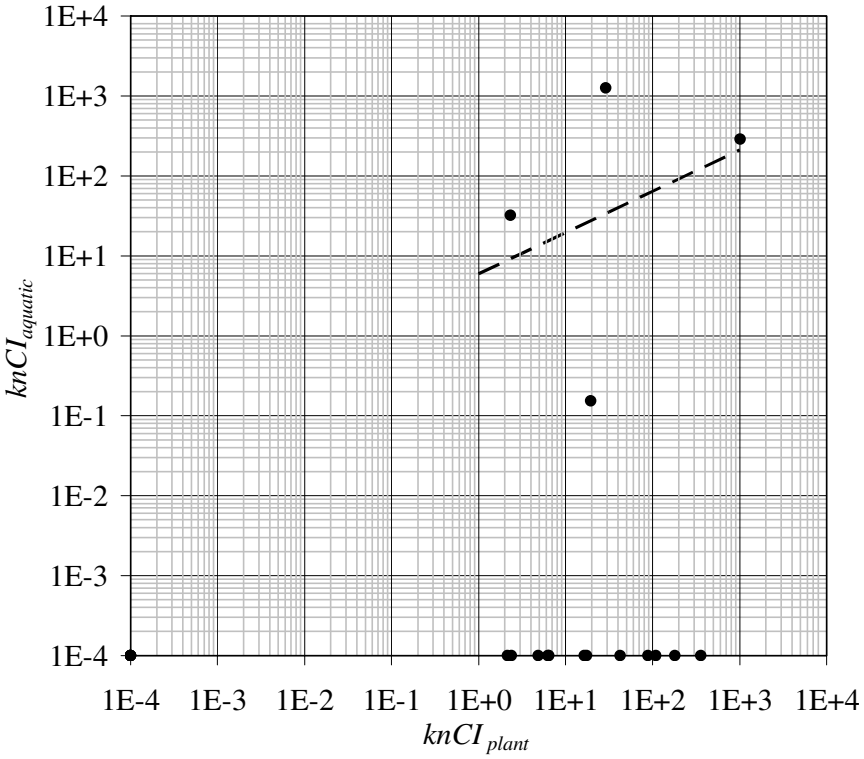

Figure 5-24 $knCI_{aquatic}$ vs. $knCI_{plant}$

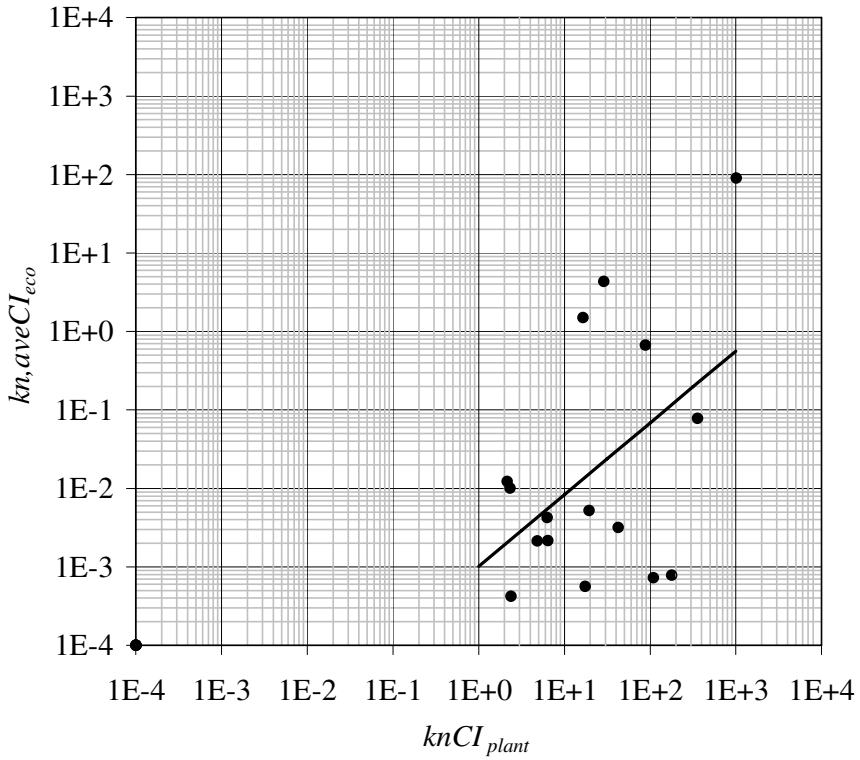

Figure 5-25 *kn,aveCI*$_{eco}$ vs. *knCI*$_{plant}$

5.3.2 Potential Scenario

Figure 5-26 to Figure 5-33 are a series of log-log plots relating the cumulative hazard indices for each of the 7 ecological receptors plus average ecological receptor indices, *po,aveCI*$_{eco}$, to human receptor cumulative hazard indices under the potential scenario. In general, the correlations aren't as strong as those under the known scenario and, referring to Table 5-7, only *CI* values for cows, voles, shrews, and aquatic life as well as *po,aveCI*$_{eco}$, have acceptable correlations with human indices, *poCI*$_{human}$.

Table 5-7 $poCI_k$ vs. $poCI_{human}$ correlation statistics

$poCI_k$	r_p	n	t	t_a	Correlation acceptable?
$poCI_{human}$	-	-	-	-	-
$poCI_{plant}$	0.23	15	0.86	1.77	No
$poCI_{micro}$	0.19	9	0.52	1.89	No
$poCI_{cow}$	0.81	7	3.11	2.02	Yes
$poCI_{vole}$	0.70	8	2.37	1.94	Yes
$poCI_{shrew}$	0.77	8	2.93	1.94	Yes
$poCI_{kestrel}$	0.39	5	0.74	2.35	No
$poCI_{aquatic}$	0.67	9	2.39	1.89	Yes
$po,aveCI_{eco}$	0.63	17	3.10	1.75	Yes

The following regression equations describe the relationships and represent a band of probable results having widths ranging from 2 to 5 orders of magnitude.

Equation 5-23 $\log(poCI_{cow}) = [0.87\log(poCI_{human}) - 2.4] \pm 1; \quad 10 < poCI_{human} < 30{,}000$

Equation 5-24 $\log(poCI_{vole}) = [0.90\log(poCI_{human}) - 2.7] \pm 1.5; 10 < poCI_{human} < 30{,}000$

Equation 5-25 $\log(poCI_{shrew}) = [1.3\log(poCI_{human}) - 3.2] \pm 1.5; 10 < poCI_{human} < 30{,}000$

Equation 5-26 $\log(poCI_{aquatic}) = [0.63\log(poCI_{human}) + 0.34] \pm 1.5; 3 < poCI_{human} < 30{,}000$

5-27 $\log(po, aveCI_{eco}) = [0.80\log(poCI_{human}) - 3.4] \pm 2.5; 0.1 < poCI_{human} < 30{,}000$

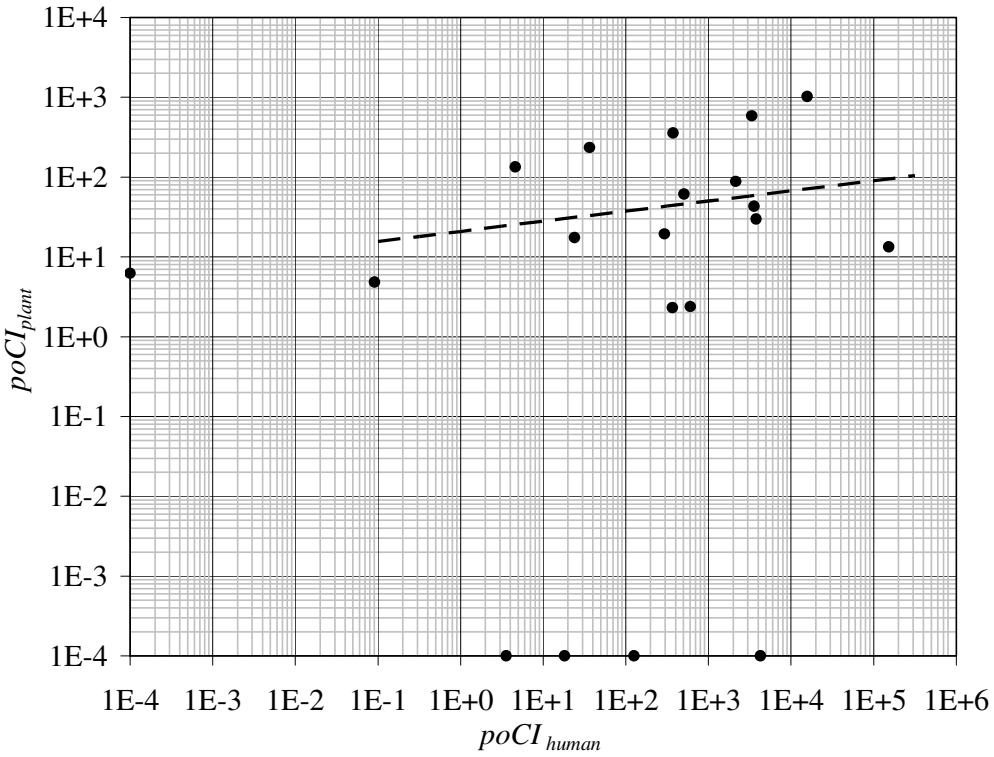

Figure 5-26 *poCI*$_{plant}$ vs. *poCI*$_{human}$

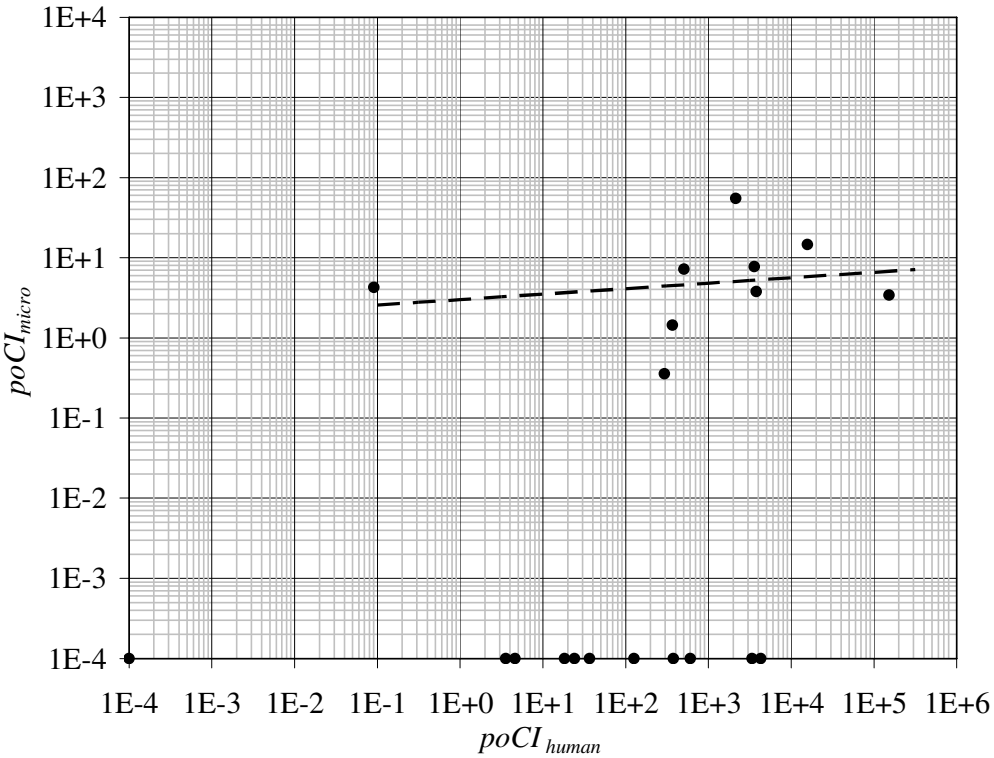

Figure 5-27 *poCI*$_{micro}$ vs. *poCI*$_{human}$

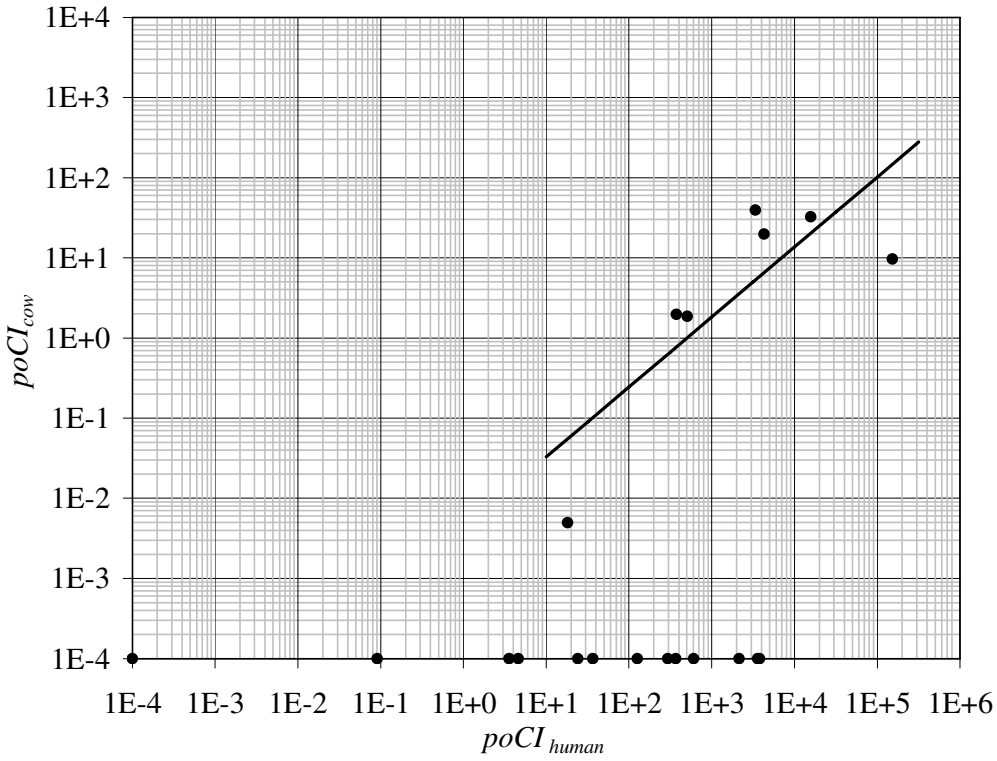

Figure 5-28 *poCI*$_{cow}$ vs. *poCI*$_{human}$

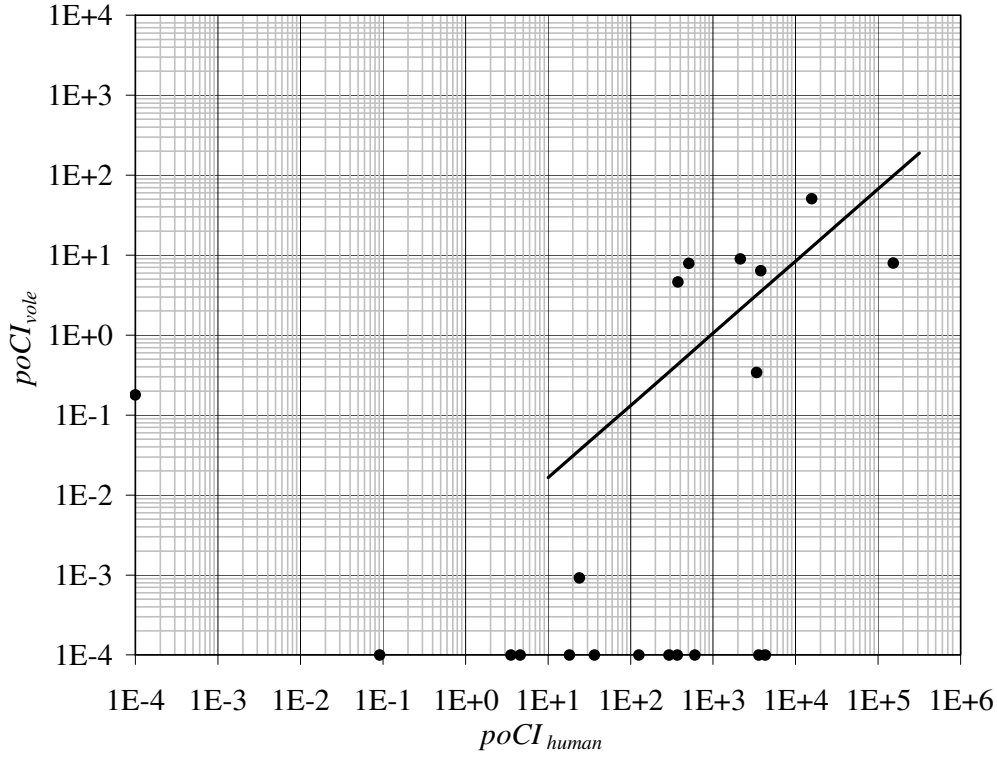

Figure 5-29 *poCI*$_{vole}$ vs. *poCI*$_{human}$

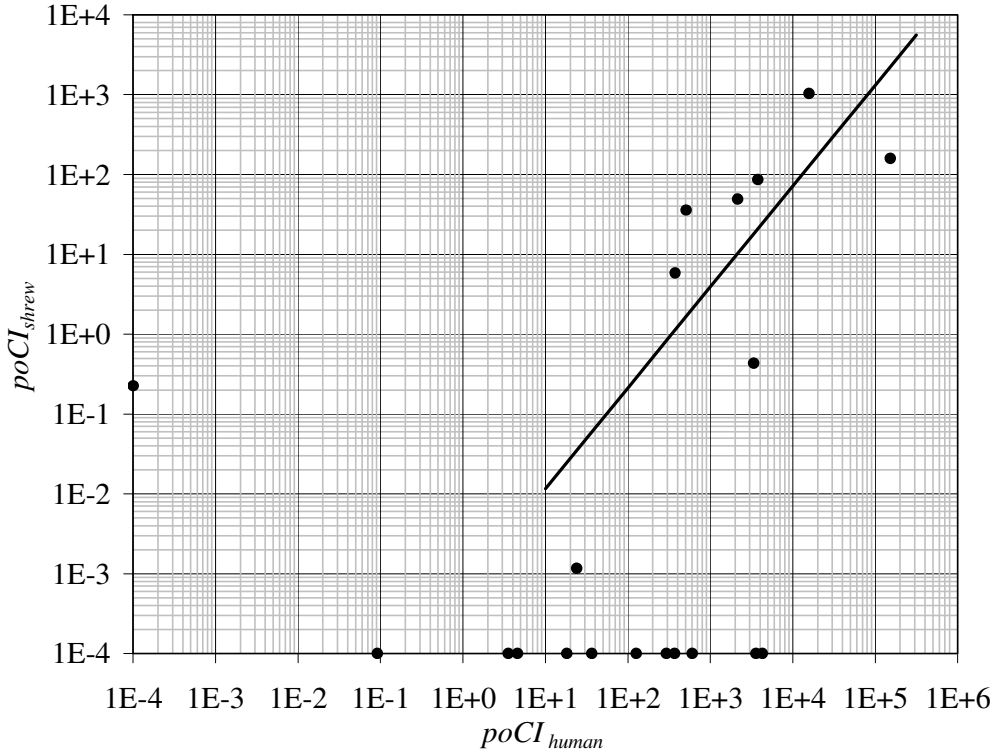

Figure 5-30 *poCI*$_{shrew}$ vs. *poCI*$_{human}$

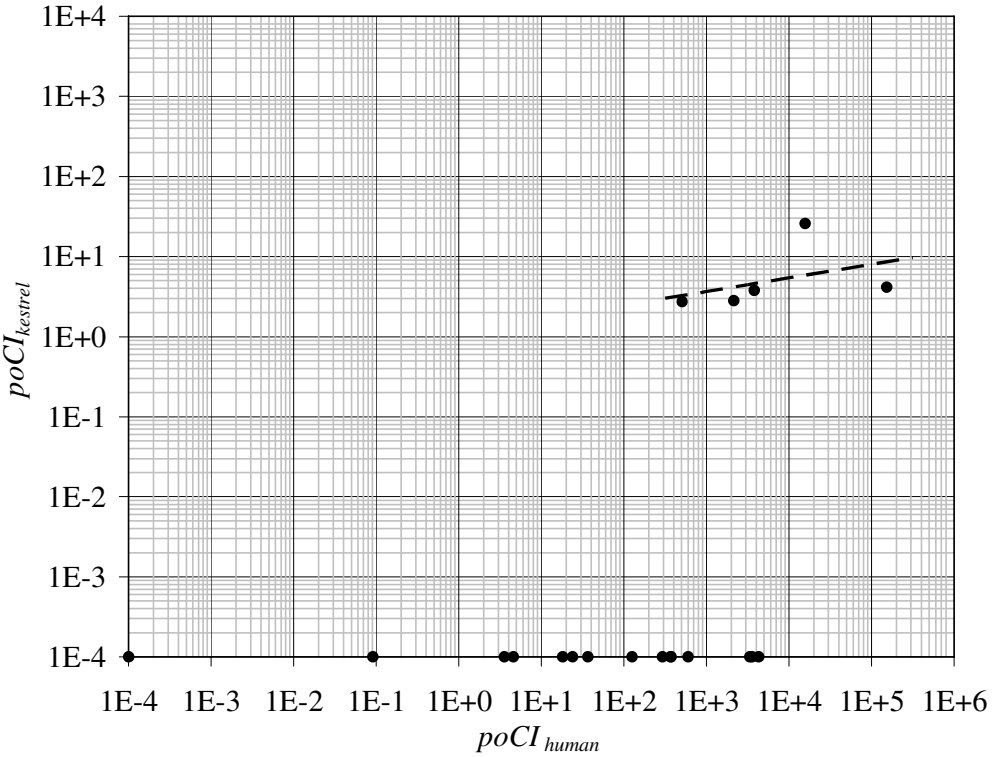

Figure 5-31 *poCI*$_{kestrel}$ vs. *poCI*$_{human}$

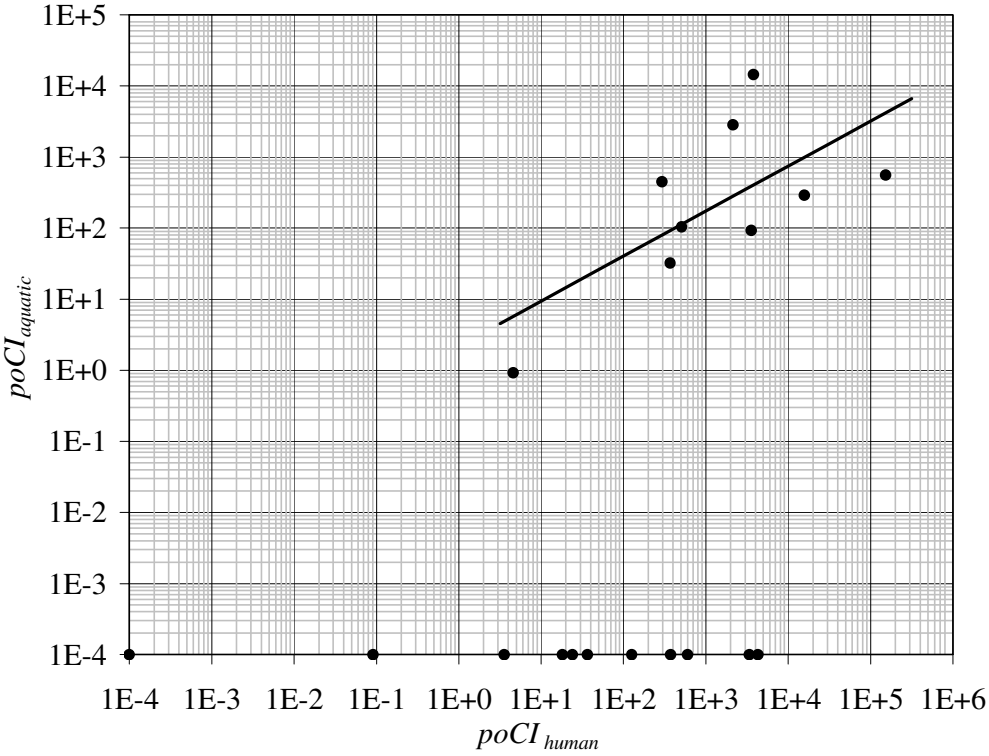

Figure 5-32 *poCI*$_{aquatic}$ vs. *poCI*$_{human}$

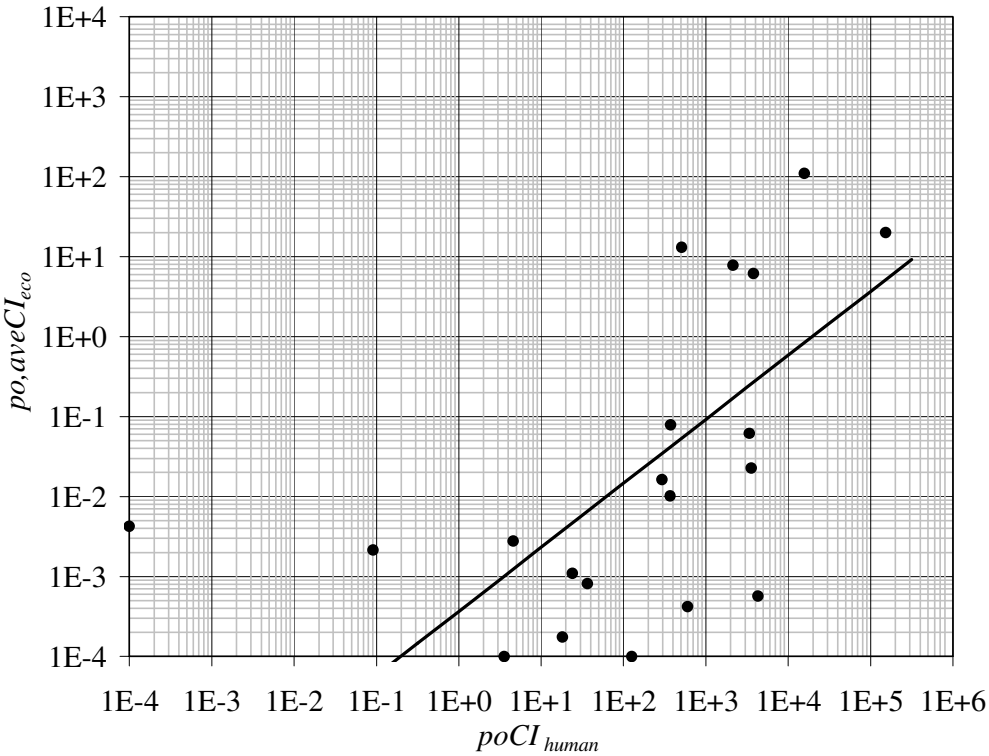

Figure 5-33 *poCI*$_{eco}$ vs. *poCI*$_{human}$

Finally, Figure 5-34 to Figure 5-40 are a series of log-log plots relating ecological receptor cumulative hazard indices to plant & invertebrate cumulative hazard indices under the potential scenario. Correlations are marginal at best based on visual inspection and confirmed through the statistical test mentioned previously and summarised in Table 5-8. Thus, equations are not proposed.

Table 5-8 $poCI_k$ vs. $poCI_{plant}$ correlation statistics

$poCI_k$	r_p	n	t	t_a	Correlation acceptable?
$poCI_{human}$	0.23	15	0.86	1.77	No
$poCI_{plant}$	-	-	-	-	-
$poCI_{micro}$	0.59	9	1.92	1.89	Marginal
$poCI_{cow}$	0.42	5	0.81	2.35	No
$poCI_{vole}$	0.42	9	1.23	1.89	No
$poCI_{shrew}$	0.34	9	0.96	1.89	No
$poCI_{kestrel}$	0.80	5	2.30	2.35	No
$poCI_{aquatic}$	-0.04	9	-0.09	-1.89	No
$po,aveCI_{eco}$	0.40	16	1.64	1.76	No

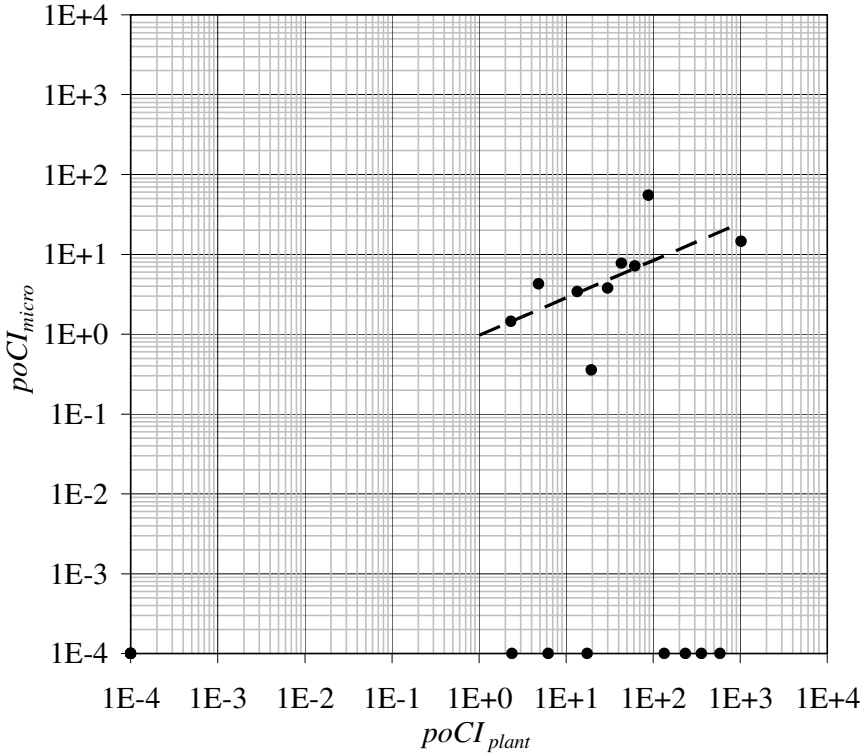

Figure 5-34 *poCI$_{micro}$ vs. poCI$_{plant}$*

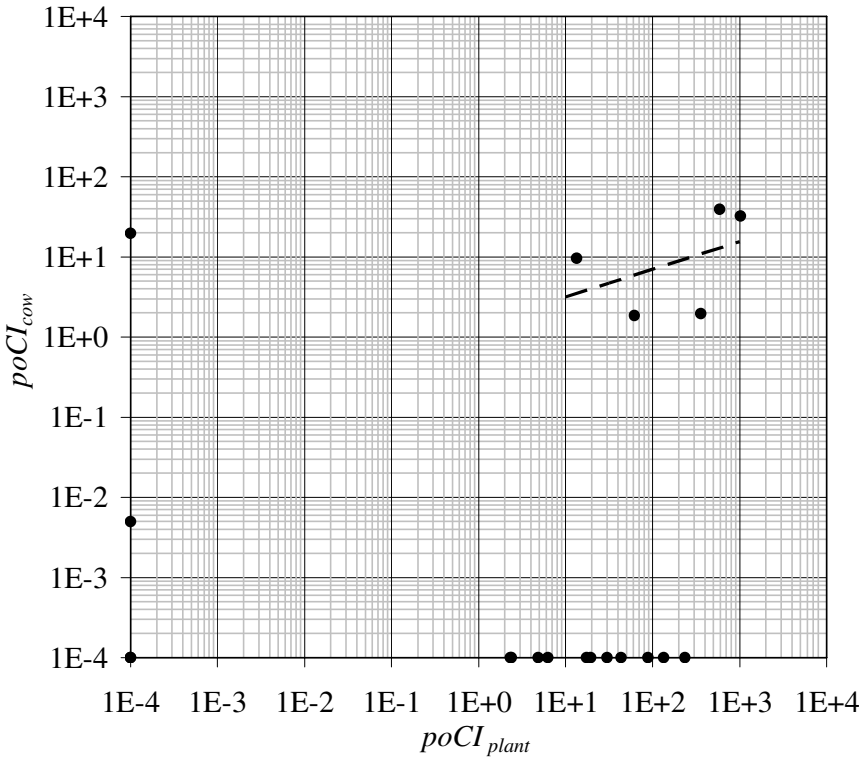

Figure 5-35 *poCI$_{cow}$ vs. poCI$_{plant}$*

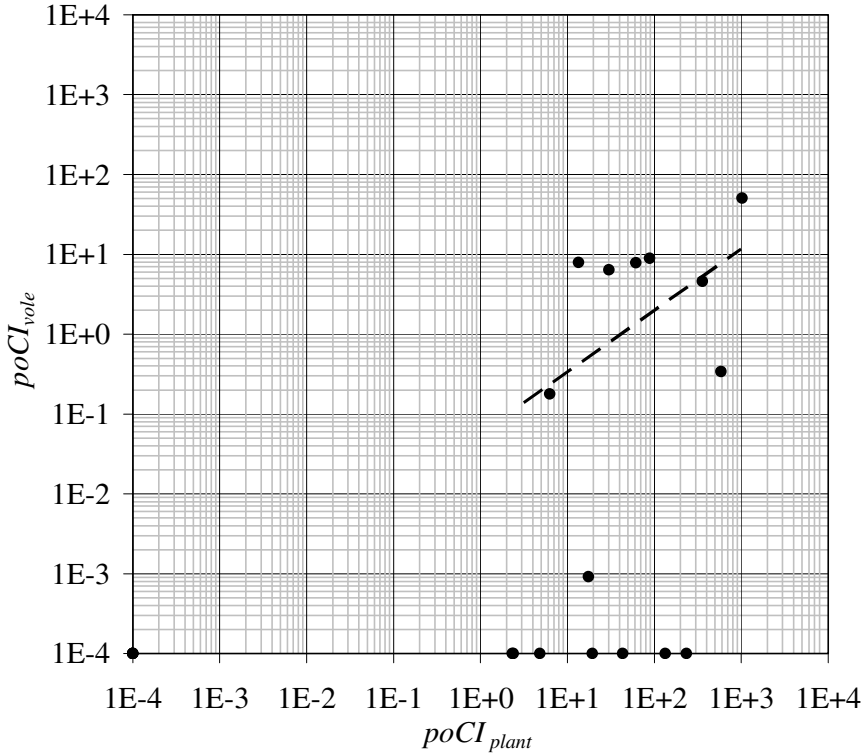

Figure 5-36 *poCI$_{vole}$ vs. poCI$_{plant}$*

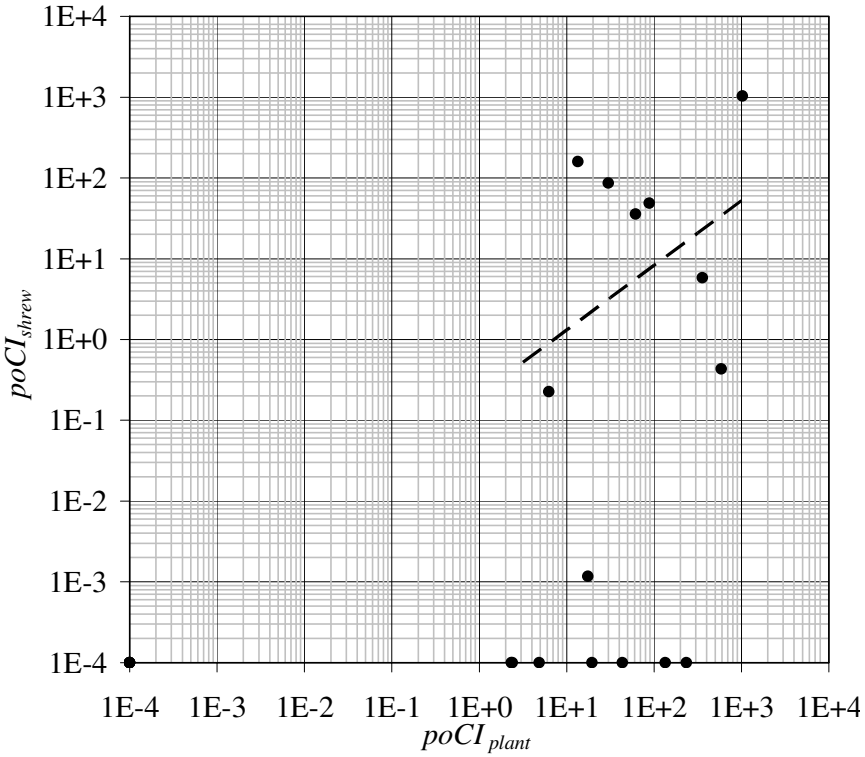

Figure 5-37 *poCI$_{shrew}$ vs. poCI$_{plant}$*

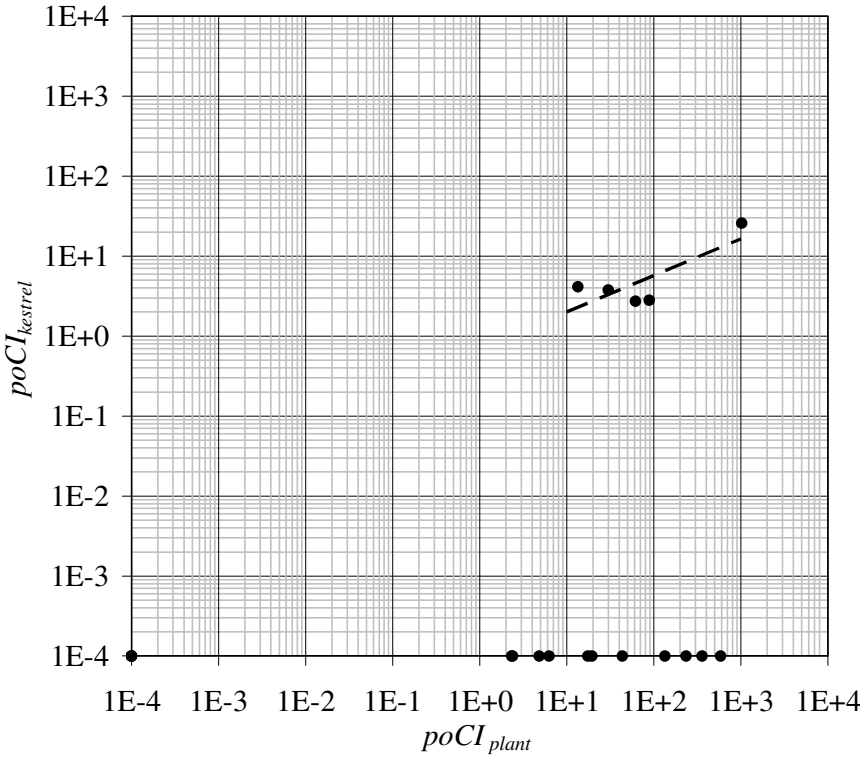

Figure 5-38 *poCI$_{kestrel}$ vs. poCI$_{plant}$*

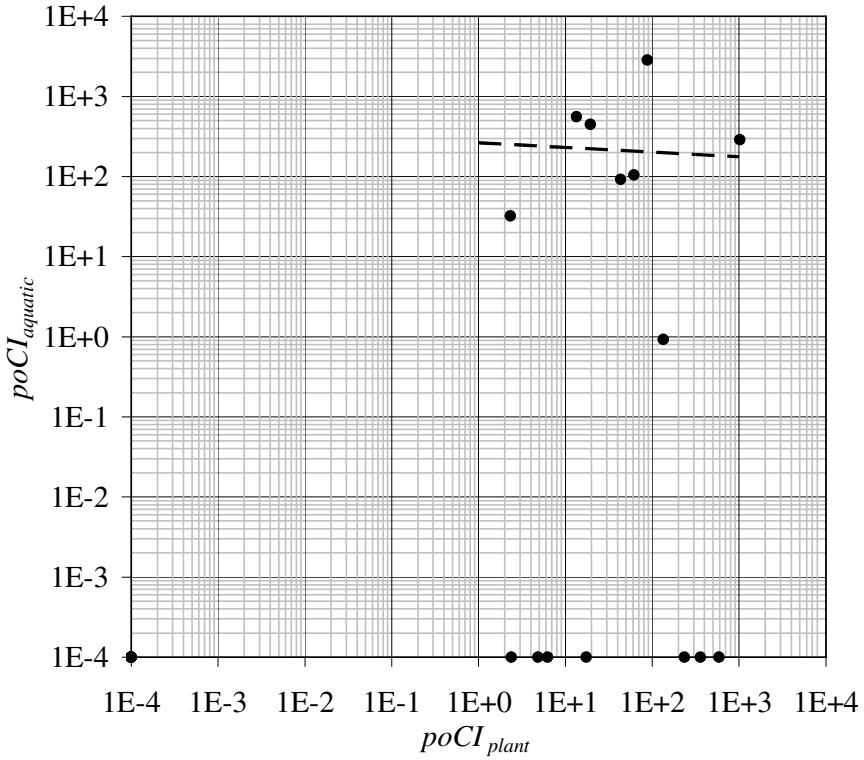

Figure 5-39 *poCI$_{aquatic}$ vs. poCI$_{plant}$*

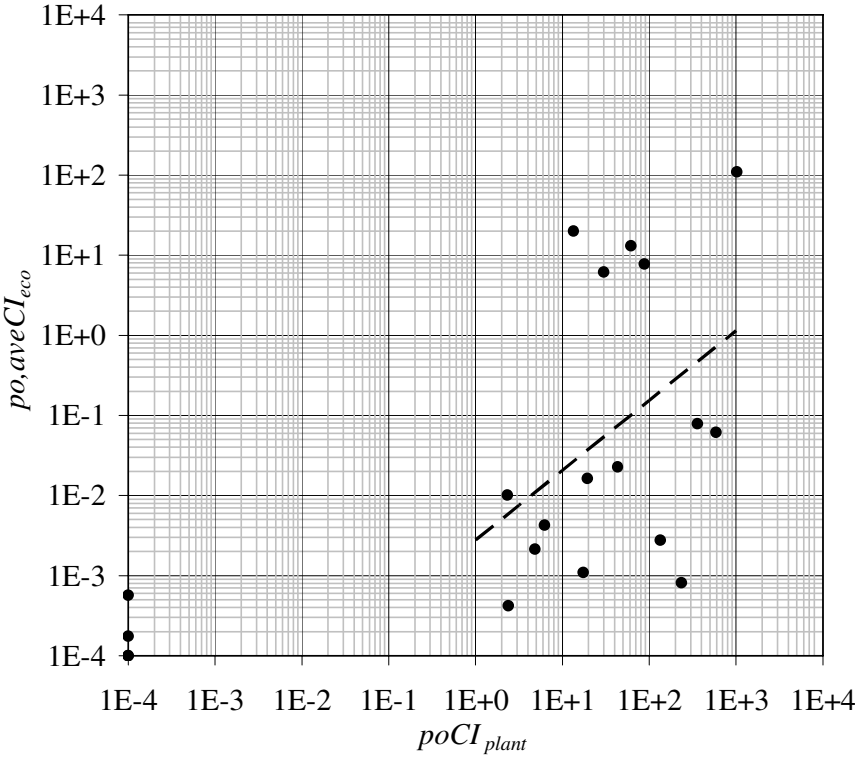

Figure 5-40 *po,aveCI$_{eco}$ vs. poCI$_{plant}$*

5.4 Conclusions

Based on the results, three conclusions can be made. First, cumulative hazard indices for humans can act as surrogates for some ecological receptors or receptor groups. Under the defined known scenario, human *CI* values are positively correlated with those for plants & soil invertebrates, cows, voles, shrews, kestrels, aquatic life, and the geometric average of ecological receptor *CI* values. Under the potential scenario, human *CI* values are also positively correlated with the same receptors or receptor groups except for plants & invertebrates and kestrels; however, the correlations are not as strong as under the known scenario. Equations that can be used to predict the range of probable ecological receptor *CI* values using human *CI* values have been developed. The equations associated with the known scenario are preferred for use because they exhibit stronger

agreement with the data when compared to equations related to the potential scenario. Second, plants & soil invertebrate *CI* values can also act as surrogates for the following ecological receptor or receptor groups, although the list is limited to the known scenario: cows, voles, shrews, kestrels, and average ecological receptor *CI* values. Third, based on the first two conclusions, humans are the preferred surrogate for ecological receptors.

The validity of these conclusions is dependent on the conditions that both surrogate and represented receptors must be present at the contaminated site; there are operable exposure routes between contaminants and both surrogate and represented receptors; and, there are defined tolerable doses for at least some of the chemicals to which both surrogate and represented receptors are exposed.

The conclusions presented in this research must be further validated with data from additional contaminated sites.

Chapter Six: An Evaluation of the 2008 National Classification System for Contaminated Sites

6.1 Introduction

In 1992, the Canadian Council of Ministers of the Environment (CCME) published the National Classification System for Contaminated Sites (NCSCS) to assist federal departments and agencies in prioritizing contaminated site management funding (CCME 1992). This system was subsequently revised in 2008. In this chapter we investigate the ability of the 2008 NCSCS to emulate preliminary human health and ecological risk assessment results for contaminated sites. A number of contaminated sites were selected from the Federal Contaminated Site Inventory (FCSI) (TBCS 2005) and were evaluated based on the NCSCS and also on preliminary human health and ecological risk assessments.

6.2 Overview of the NCSCS

CCME provides detailed instructions on the 2008 NCSCS in its *Guidance Document* (2008c) and Figure 6-1 is a reprint from it that summarises the structure of the NCSCS. A user categorises a contaminated site by assigning scores to each of 65 evaluation factors that are grouped into the 16 subcategories listed in Figure 6-1. Subcategories are divided into three site characteristic categories: contaminant characteristics (5 subcategories), migration potential (6 subcategories), and receptors (5 subcategories).

For each subcategory, the user assigns a score that is either “known” or “potential”. “Known is defined as scores that are assigned based on documented scientific and/or technical observations and potential refers to scores that are assigned

when something is not known, although it may be suspected" (CCME 2008c). For each subcategory, a range of scores can be assigned.

The range of allowable scores for each evaluation factor varies with larger ranges being assigned to factors that are deemed to have greater relevance to the overall hazard at a contaminated site. In cases where there is insufficient information to assign a score, the response is "do not know" and a score which is one half of the maximum allowable score is entered. This estimated score is considered an uncertain value for the evaluation factor.

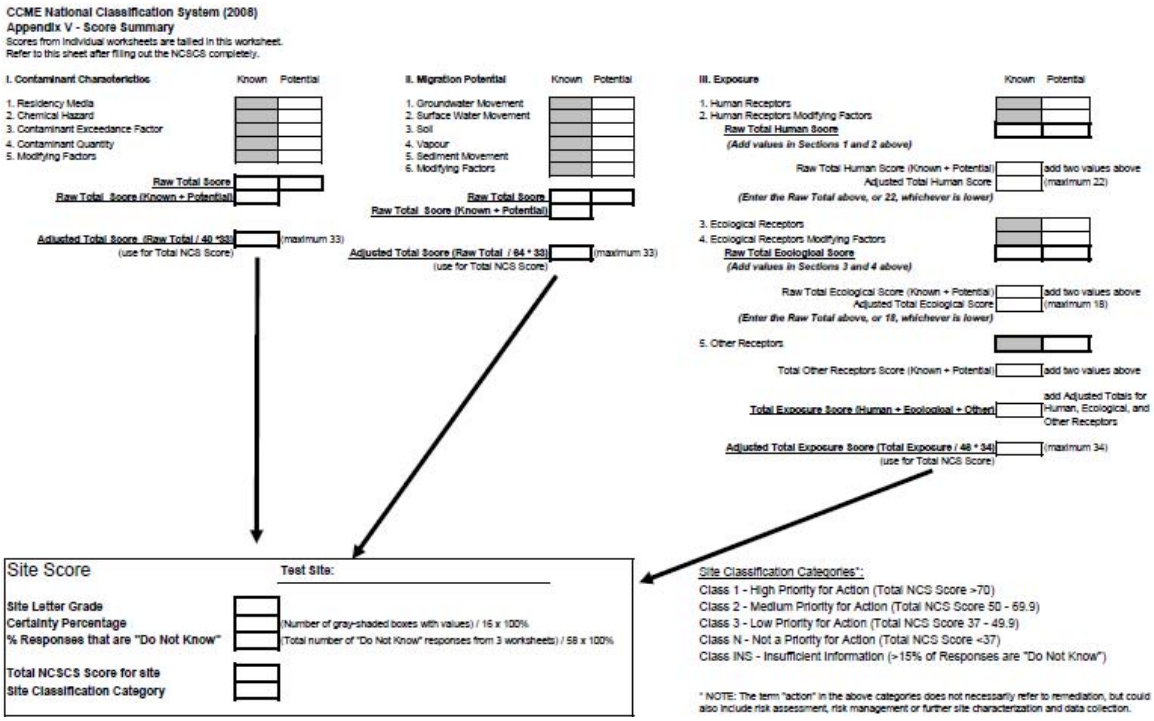

Figure 6-1 NCSCS structure reprinted with permission from CCME (2008c)

Once scores have been assigned to each evaluation factor, they are combined to determine category scores ranging up to 33, 33, and 34 for Contaminant Characteristics, S_{con}; Migration Potential, S_{mig}, and Exposure, S_{exp}, respectively. These scores are added to yield an overall site score, S_{site}, ranging up to 100. The site score is then used to classify

the contaminated site into one of 4 classes, if sufficient information is provided (CCME 2008c):

- Class 1 – High Priority for Action, $S_{site} \geq 70$
- Class 2 – Medium Priority for Action, $50 \leq S_{site} \leq 69.9$
- Class 3 – Low Priority for Action, $37 \leq S_{site} \leq 49.9$
- Class N – Not a Priority for Action, $S_{site} < 37$

The basis for the class cut off values is not discussed by CCME.

The NCSCS has several strengths. First, it is easy to use, intuitive, and explicitly considers contaminant characteristics, migration potential, and exposure pathways in calculating a site score, thus aligning itself with the source-path-receptor model used in environmental risk assessment. Second, score calculation uncertainty is considered by expressing the known and potential scores as a ratio where 1 indicates low or no uncertainty and zero indicates high uncertainty. Third, the use of an information uncertainty letter grade, where *A* indicates that the score is based on remediation reports and *F* indicates anecdotal information was used, is an attempt to communicate data reliability to decision makers. Fourth, the layout of the summary score sheet is concise and allows a decision maker to quickly determine what factors influence the final score and to view the uncertainty in those factors.

A potential weakness of the NCSCS is the site score is determined by adding the contaminant characteristics, migration potential, and exposure pathways scores together. Although the NCSCS is not intended as a replacement for contaminated site human health and ecological risk assessments, a reasonable expectation is for NCSCS scores to generally agree with human health and ecological risks posed by a site. If the site score

can be generalised to a site risk, then addition implies site risk is a function of contaminant characteristics OR migration potential OR exposure pathways. This contradicts the generally accepted risk equation where risk depends on the presence of a source AND path AND receptor. All three factors must be present to incur a risk.

Another potential weakness is that known and potential scores within a subcategory are mutually exclusive. Referring to CCME's definition of known and potential (2008c), a common situation that occurs when conducting an initial Phase II ESA is the data confirms the site is contaminated but there is insufficient data to identify the extent of contamination. Nonetheless, the assessor may suspect the potential magnitude of the contaminated area based on an understanding of the initial conceptual site model and the assessor's experience at other sites. A more reasonable understanding may be known and potential scores are the assumed lower and upper bounds of a range of scores based on available information.

6.3 Methods

6.3.1 Contaminated Site Selection

Contaminated sites under the jurisdiction of federal departments or agencies were chosen because the NCSCS or a variant was used to classify these sites. The FCSI is a database containing information on over 19,000 contaminated sites that are the responsibility of the Government of Canada (TBCS 2005). Amongst these sites, approximately 8,000 of them have been classified as high, medium, low, or not a priority for action using the NCSCS. The FCSI was used to search for and select candidate sites based on four criteria:

- the sites should represent the more frequently encountered contaminant types;

- the sites should represent the varied climate and geography across Canada;
- at minimum, a Phase II ESA must have been completed at each site; and,
- the sites should represent NCSCS Classes 1, 2, 3, and N.

Figure 6-2 shows the proportions of sites impacted by various contaminant types. Almost 90% of contaminated sites have soil impacted by metals; petroleum hydrocarbons (PHCs) including benzene, toluene, ethylbenzene, xylenes (BTEX); or polycyclic aromatic hydrocarbons (PAHs). Thus, the selected sites focused on these contaminants.

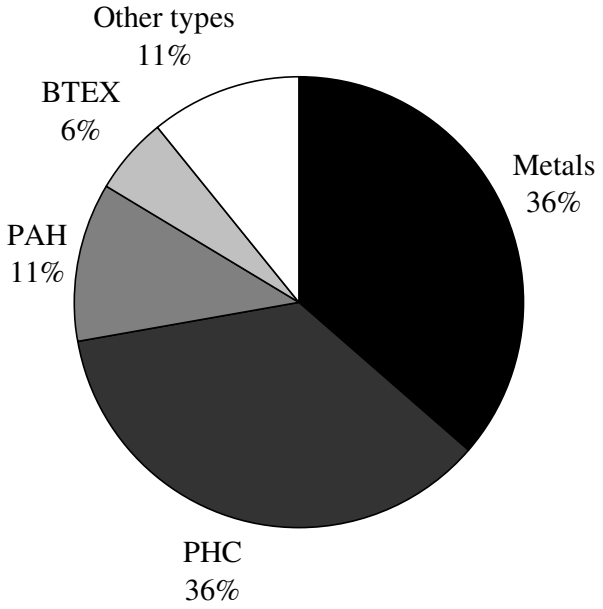

Figure 6-2 Occurrence of contaminant types in FCSI

Sites were chosen from the Northwest Territories, Nunavut, and Yukon to represent Canada's North; sites in British Columbia and the Alberta Foothills to represent the West Coast and Rocky Mountains; sites in Saskatchewan and Manitoba for the Prairies; sites in Ontario for Central Canada; and sites in the Atlantic Provinces for the Canadian Maritimes. To meet the third criterion, sites were selected from a list of those that met *Step 6 – Detailed Testing Program* of the Federal 10 Step Process (CSMWG

1999). To meet the fourth criterion, each of the four NCSCS classes was represented by approximately an equal number of sites by using the class assignments listed in the FCSI as a guide.

Twenty sites were selected from the FCSI and environmental site assessment (ESA) information was requested via the federal *Access to Information Act* (GoC 1985). Table 6-1 briefly summarises information on the selected contaminated sites. Ecoregions are as defined by NRCan (2009). The reports are publicly available and were prepared by the following entities: AMEC (2004a,b, 2005, 2008); Azimuth, Golder, and SNC (2007, 2008); Bryant (2003); EMS (2004a,b); Franz (2005, 2006); Golder (2001); Hemmera (2001, 2002); JWAL (1991, 1993); JWEL (1998, 2002); JWL (2004, 2006); JASA (2007); KGS (2002, 2003a,b); Meridian (2006, 2007a,b); NRCC (2007, 2008); OMM (1997, 1998, 1999); Parks Canada (2007); PGL (2002, 2006); RMC (2001); SEACOR (2006a,b); SNC (2007, 2008a,b); Teranis (2007a,b); UMA (2008); and Wardrop (1997).

Table 6-1 Selected contaminated sites

Site Id	Contaminant Source	Province or Territory	Ecoregion	Contaminant Types	Federal Step	NCSCS Class
1	Waste soil landfill	BC	Eastern Vancouver Island	Metals, PCBs, PAHs, PHCs	8	N
2	Above ground storage tank	BC	Western Vancouver Island	PAHs, PHCs	8	2
3	Weathered paint	ON	Manitoulin-Lake Simcoe	Metals	8	2
4	Mechanical repair area	BC	Coastal Gap	Metals, PAHs, PHCs	6	2
5	Above ground storage tank	YT	Ruby Ranges	PAHs, PHCs	9	2
6	Waste dump	BC	Eastern Vancouver Island	Metals, PAHs, PCBs, PHCs	7	1
7	Soak away pit	ON	St. Laurent Lowlands	CHCs	6	3
8	Salt storage area	AB	Northern Continental Divide	Salts	9	2
9	Underground storage tank	PE	Prince Edward Island	Metals, PAHs, PHCs	8	N
10	Spilled fuel	NB	Maritime Lowlands	Metals, PAHs, PHCs	7	3
11	Chemical dump	ON	St. Laurent Lowlands	CHCs, Metals, PHCs	6	1
12	Underground storage tank	ON	Thunder Bay-Quetico	PHCs	8	N
13	Above ground storage tank	MB	Aspen Parkland	PHCs	8	N
14	Underground storage tank	SK	Aspen Parkland	PHCs	6	3
15	Wastewater lagoon	SK	Aspen Parkland	PHCs	6	3
16	Pesticide dump	SK	Aspen Parkland	Metals, Phenols	6	3
17	Equipment dump	NU	Eureka Hills	Metals	6	3
18	Above ground storage tank	NT	Tazin Lake Upland	PHCs	9	N
19	Waste dump	AB	Fescue Grassland	DDT, Metals, PAHs	6	1
20	Above ground storage tank nest	NT	Tuktoyaktuk Coastal Plain	PHCs	7	1

6.3.2 Preliminary Quantitative Risk Assessment Model

Since the NCSCS is a screening tool intended to classify contaminated sites using readily available site information, a reasonable assumption is to evaluate it by applying preliminary or screening level risk assessments using similar input data. Health Canada describes a preliminary quantitative risk assessment (PQRA), in the context of human receptors, as a screening assessment that uses "prescribed methods and assumptions that ensure that exposures and risks are not underestimated" (2004a). CCME describes a screening ecological risk assessment as a tier 1 risk assessment "based primarily on data from literature, previous or preliminary studies of the contaminated site, monitoring studies, historical data of the site, and a reconnaissance visit to evaluate the receptors, exposure, hazards, and risk at the site" (1996). For the purposes of this study, both screening human health and ecological risk assessments are referred to as a PQRA. Both Health Canada (2004a) and CCME (1996, 1997) identify the major elements of a PQRA as: problem formulation (also known as a conceptual site model), exposure assessment, hazard (or toxicity) assessment, and risk characterization. This structure was adopted in providing an overview of the PQRAs applied in this paper.

6.3.2.1 Conceptual Site Model

Biological receptors identified by CCME (2006) and Alberta Environment (2009a,b) were used in the PQRAs. The relevant human receptors are the toddler, aged 7 months to 4 years old, for threshold effect contaminants and an adult, a person 18 years old or greater, for non-threshold effect contaminants (e.g. carcinogens) (HC 2004a). The following ecological receptors groups were used in the PQRAs:

- terrestrial plants and soil invertebrates;

- soil microorganisms responsible for nutrient and energy cycling;
- agricultural livestock;
- wildlife including primary, secondary, and tertiary consumers; and,
- aquatic life.

Consistent with CCME (2006, 2008a,b) and AENV (2009a), a dairy cow was used as the surrogate ecological receptor for livestock. Similarly, CCME and AENV consider the meadow vole (*Microtus pennsylvanicus*) to be the surrogate primary consumer, mammal species in developing soil remediation guidelines and was used as a surrogate species in the PQRAs.

Based on CCME (2006) guidance, the following food chain was applied when assessing the effect of bioaccumulating contaminants: soil → earthworm → secondary consumer → tertiary consumer. Consistent with CCME (2008b), the masked shrew (*Sorex cinereus*) was the surrogate secondary consumer chosen for the PQRAs. The American kestrel (*Falco sparverius*) was the chosen surrogate, tertiary consumer used in the PQRAs because it includes small mammals such as shrews in its diet (USEPA 1993) and because this species is referenced in soil quality guidelines published by federal (EC 2001) and provincial environmental agencies (OMOE 2008).

A polar coordinate system was used to spatially reference contaminated site data in ESA reports and was selected to simplify contaminant transport calculations. The origin was positioned within the contaminant source zone where the majority of detected contaminants were at their maximums. A site was then divided into cells each identified by its direction and radius from the origin. At each cell, soil was divided vertically into three strata where topsoil was defined as the top 0.3 m, surface soil as between 0.3 metres

and 1.5 metres below ground surface (mbgs), and subsoil below 1.5 mbgs. The depth definitions of surface soil and subsoil are consistent with definitions proposed by CCME (2006).

Each cell was assigned one of seven land uses to determine the relevant receptors and exposure parameters. The following land uses as defined by CCME (2006) were used in the PQRAs: agricultural, residential, parkland, commercial, and industrial. In addition to the CCME land uses, a natural area land use as defined by AENV (2009a) was used in the PQRAs to accommodate contaminated sites located in remote areas not expected to be occupied by humans. Finally, areas capable of sustaining an aquatic ecosystem were defined as "water". The selection of land uses for a site was based on information in the associated ESA reports, aerial imagery, and land use zoning maps, where available.

Additional cell attributes included the presence or absence of habitable buildings and types of groundwater usage. The presence of habitable buildings near contaminated soil or groundwater creates potential for indoor air quality issues for occupants due to contaminant vapours infiltrating the building. Contaminated groundwater used as potable water, for livestock watering, or crop irrigation increases risk to humans, livestock, and irrigated crop production.

Meteorological data needed for the PQRA model was obtained from Environment Canada (2010) for a weather station in the vicinity of each contaminated site.

6.3.2.2 Exposure Assessment

Chemical properties information was needed to predict how contaminants behaved and were transported through and across media and data were obtained from the following sources: AENV (2009a), Baes *et al*. (1984), BCMELP (1996), CCME

(2008a,b, 2009), Gustafson *et al*. (1997), Health Canada (2004a), Mackay *et al*. (2006), ORNL (2009), Travis & Arms (1988), and USEPA (1996, 2005, 2009a,b).

Exposure routes for each of the identified receptors are as defined by CCME (2006) and AENV (2009a). Exposure durations, physiological parameters, and media or food specific exposure parameters for human receptors were obtained from Health Canada (2004a) and CCME (2006). Ecological receptor exposure assumptions were based on CCME (2006) and AENV (2009a) with input from USEPA (1997).

Human exposure equations provided by Health Canada (2004a) were used in calculating predicted daily intake values at each cell via soil ingestion, particulate inhalation, vapour inhalation, water ingestion, soil contact with skin, and contaminated food ingestion.

Regarding ecological receptor exposure, soil contact doses for plants & soil invertebrates and soil microorganisms were determined from topsoil and surface soil contaminant concentrations. Predicted daily intake values via soil, water, and food ingestion for cows and meadow voles were calculated as per CCME (2006). Likewise, predicted daily intake values for masked shrew and American kestrel via contaminated soil and food exposure were calculated as per CCME (2006). Water and sediment contact doses for aquatic life were the measured concentrations in water and sediment, respectively. Contaminant concentrations in plants, produce, earthworms, masked shrew, beef, and milk (i.e., receptor food sources) were also calculated using equations from or based on CCME (2006).

The contaminant transport models and assumptions recommended by CCME (2006) and Health Canada (2004a) and AENV (2009b) were used as a basis in predicting

the transport of contaminants via groundwater, vapour, wind, and surface water runoff. These models are simplifications of actual transport process but are appropriate given the limited information typically available for most contaminated sites.

6.3.2.3 Toxicity Assessment

Health Canada (2004b, 2006b), CCME (2008a,b, 2009), and AENV (2009a) were the Canadian sources for human toxicity data and USEPA (2009c) and ORNL (2009) were the sources from the United States. Ecological receptor toxicity information was obtained from CCME (2008b, 2009), AENV (2009a), and USEPA (2009b).

6.3.2.4 Risk Characterization

At each cell, the hazard posed by each contaminant, to each receptor, via each exposure route was expressed as a dimensionless hazard quotient, $HQ_{i,j,k,m}$, which is the measured or predicted dose divided by the tolerable dose (Suter 2007). For human and terrestrial animal receptors, $HQ_{i,j,k,m}$ was expressed as predicted daily intake divided by tolerable daily intake. For terrestrial plants, soil invertebrates, and microorganisms, the ratio of measured or predicted soil concentration to tolerable soil concentration defined $HQ_{i,j,k,m}$. For aquatic plants and animals, $HQ_{i,j,k,m}$ was expressed as measured or predicted water and sediment concentrations divided by tolerable water and sediment concentrations, respectively.

The hazard quotient approach is appropriate where the dose vs. effect curve for a contaminant is not available or required (Suter 2007), as is the case with the PQRAs. Typically, hazard quotients are used to characterise the hazards associated with threshold effect contaminants (i.e. non-carcinogens) and risk values (e.g. 10^{-4} probability) used to describe non-threshold effect contaminants (HC 2004a). However, to permit combining

hazards due to both carcinogenic and non-carcinogenic contaminants, the hazards associated with carcinogenic contaminants were also expressed as hazard quotients. A limitation of this simplification is carcinogenic risk values are not explicit in the calculation. If necessary, these risk values can be back calculated by multiplying the carcinogenic $HQ_{i,j,k,m}$ by the acceptable risk level of 10^{-5} (HC 2004a). A hazard quotient does not convey a likelihood or probability of an adverse effect upon a biological receptor but is a measure of the potential for adverse effect where a higher *HQ* means a higher adverse effect potential without quantifying that potential in an absolute sense.

Similar to the approach proposed by USEPA (2005), hazard quotients were combined across contaminants to obtain a hazard index, $HI_{i,k,m}$, for a given receptor and exposure route at each cell. Then, $HI_{i,k,m}$ values were combined across exposure routes for a given receptor to obtain a cumulative hazard index, $CI_{i,k}$, for each receptor at each cell. Finally, the maximum $CI_{i,k}$ value for each receptor was used to characterise receptor hazard, CI_k.

Equation 6-1

$$CI_k = \max\left(\sum_{m=1}^{d}\sum_{j=1}^{b} HQ_{i,j,k,m}\right)_{i=1}^{a}$$

where: i = cell "i"; j = contaminant "j"; k = receptor "k"; and m = exposure route "m"

Quantifying the overall hazard of a contaminated site to all 7 ecological receptors or receptor groups is confounded by the absence of a generally accepted protocol. Since cumulative hazard indices are normalised values based on tolerable doses or concentrations, a practical solution is to simply declare that a central tendency measure of CI_k values be used as estimators to characterise the set of 7 ecological receptor CI_k values for a contaminated site. Given that CI_k values can range over many orders of magnitude,

the geometric mean was chosen, $aveCI_{eco}$. In cases where a particular receptor had CI_k equal to zero, CI_k was set to a small number (i.e., 10^{-4}) that would not have a significant influence on the final result yet allow calculation of the geometric mean.

6.3.2.5 Scenarios

Two exposure scenarios were evaluated in the PQRAs: known and potential. In the known scenario, $knCI_k$ values were calculated for the existing combination of contaminant concentrations and their locations, current exposure routes, and land uses as supported by the ESA reports for a contaminated site. In the potential scenario, $poCI_k$ values were calculated for the potential contaminant concentrations after applying the contaminant transport models referenced previously and incorporating potential exposure routes within the defined land uses.

6.3.3 NCSCS Scoring

A NCSCS score, S_{site}, for each site was determined using the MS-Excel® worksheets and guidance provided by CCME (2008c). The objective was to test the correlation between NCSCS scores and PQRA results by referencing the same data used in completing the PQRAs.

6.4 Results & Discussion

6.4.1 Known Scenario

Figure 6-3 to Figure 6-11 are a series of semi-log plots relating the cumulative hazard indices for each of the 8 receptors plus the geometric mean of ecological receptor cumulative hazard indices, $kn,aveCI_{eco}$, to NCSCS site scores under the known scenario. Common to all plots are several outliers positioned along the horizontal axis where $knCI_k$ is negligible (i.e., $\leq 10^{-4}$). Investigation of the reasons for these outliers indicates that if a

receptor is not present under a defined land use, or if all contaminant exposure routes for a receptor are not present, or if there are no defined tolerable doses for the set of chemicals to which a receptor is exposed, then the cumulative hazard index for a receptor is zero. These outliers illustrate the environmental risk assessment concept that a contaminant source, exposure route, and receptor must all be present for a risk to exist.

Excluding these outliers, the remaining data was examined to assess whether acceptable correlations exist. Visually, there are positive correlations for $knCI_{vole}$, $knCI_{shrew}$, and $kn,aveCI_{eco}$ when compared to S_{site}. This observation is supported by the associated Student *t* statistics which satisfy a maximum Type I error probability, α, of 5% as summarised in Table 6-2. The remaining receptors $knCI_k$ values do not exhibit clear correlations with S_{site} and the corresponding figures have dashed linear regression lines to indicate this observation.

Table 6-2 $knCI_k$ vs. S_{site} correlation statistics

$knCI_k$	r_p	n	t	t_a	Correlation acceptable?
$knCI_{human}$	0.40	17	1.70	1.75	No
$knCI_{plant}$	0.37	16	1.51	1.76	No
$knCI_{micro}$	-0.01	9	-0.04	1.89	No
$knCI_{cow}$	0.79	4	1.83	2.92	No
$knCI_{vole}$	0.78	7	2.76	2.02	Yes
$knCI_{shrew}$	0.86	7	3.70	2.02	Yes
$knCI_{kestrel}$	0.70	4	1.37	2.92	No
$knCI_{aquatic}$	0.51	4	0.83	2.92	No
$kn,aveCI_{eco}$	0.60	16	2.82	1.76	Yes

Where acceptable correlations exist, the regression equations below provide an approximate relationship between receptors $knCI_k$ values and S_{site}. The ranges of S_{site} values within which the equations are valid are also specified. The equations represent a

band of probable $knCI_k$ results with approximate 90% prediction intervals ranging from 2 to 4 orders of magnitude.

Equation 6-2 $$\log(knCI_{vole}) = [0.031 S_{site} - 1.2] \pm 1; \quad 20 < S_{site} < 85$$

Equation 6-3 $$\log(knCI_{shrew}) = [0.053 S_{site} - 1.7] \pm 1; \quad 20 < S_{site} < 85$$

Equation 6-4 $$\log(kn, aveCI_{eco}) = [0.059 S_{site} - 4.7] \pm 2; \quad 20 < S_{site} < 85$$

Although the number of data points is limited, the data suggests approximate 90% prediction intervals for $knCI_k$ values at each NCSCS class cut off value as shown in Table 6-3. The abbreviations LPL, UPL, and Mid refer to the lower prediction limit, upper prediction limit, and midpoint value predicted by the equations above. Focusing on Figure 6-7 for the meadow vole and Figure 6-8 for the masked shrew, the corresponding equations predict a $knCI_k$ value of approximately 1 at S_{site} equal to 37. In this case there is agreement between the meaning of *CI* values equal to 1 and S_{site} equal to 37, both are a threshold below which a contaminant doesn't pose a hazard to a receptor and no action required. At S_{site} equal to 70, Equation 6-2 and Equation 6-3 predict a $knCI_{vole}$ value of 10 and $knCI_{shrew}$ value of 90, which are 1 and 2 orders of magnitude greater than the corresponding $knCI_k$ values at the Class N cut off.

Table 6-3 $knCI_k$ prediction intervals at NCSCS class cut off scores

Receptor or Receptor Group	NCSCS Class Cut Off Scores								
	Class N to 3: 37			Class 3 to 2: 50			Class 2 to 1: 70		
	LPL	Mid	UPL	LPL	Mid	UPL	LPL	Mid	UPL
Human	-	-	-	-	-	-	-	-	-
Plants & Invert.	-	-	-	-	-	-	-	-	-
Microorganisms	-	-	-	-	-	-	-	-	-
Cow	-	-	-	-	-	-	-	-	-
Meadow Vole	0.1	1	10	0.3	3	30	1	10	100
Masked Shrew	0.2	2	20	0.8	8	80	9	90	900
American Kestrel	-	-	-	-	-	-	-	-	-
Aquatic Life	-	-	-	-	-	-	-	-	-
Average Ecological	$<10^{-4}$	0.003	0.3	2×10^{-4}	0.02	2	0.002	0.2	20

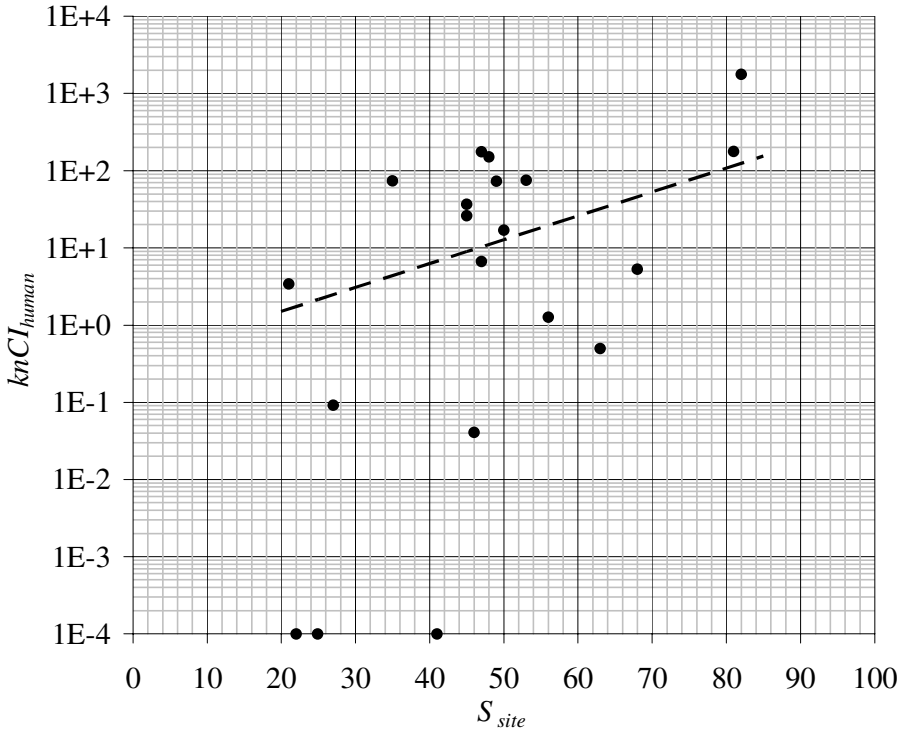

Figure 6-3 $knCI_{human}$ vs. S_{site}

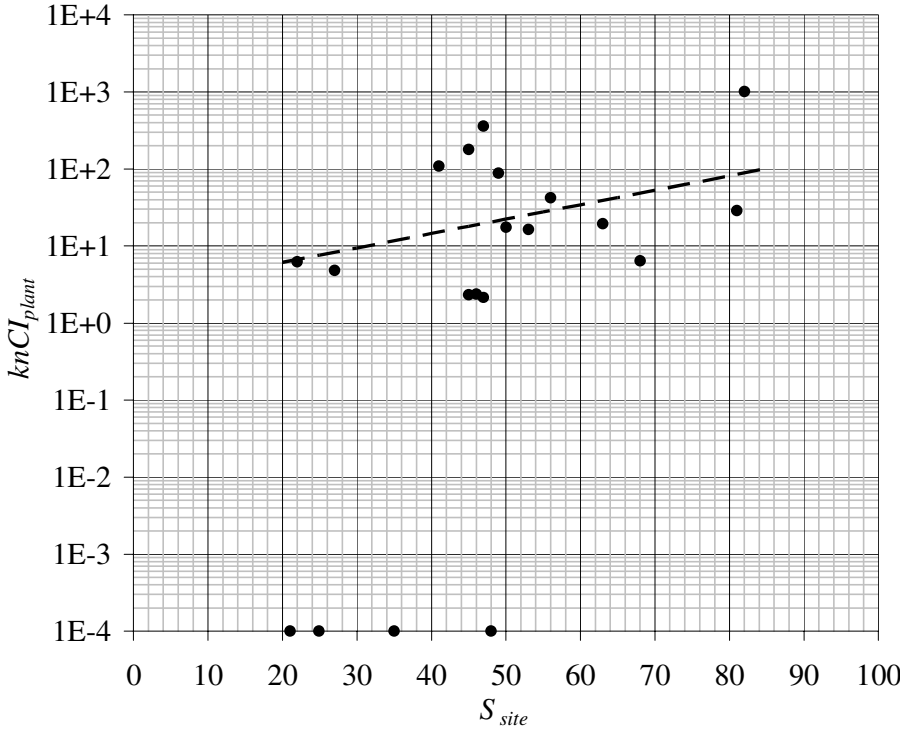

Figure 6-4 *knCI$_{plant}$* vs. *S$_{site}$*

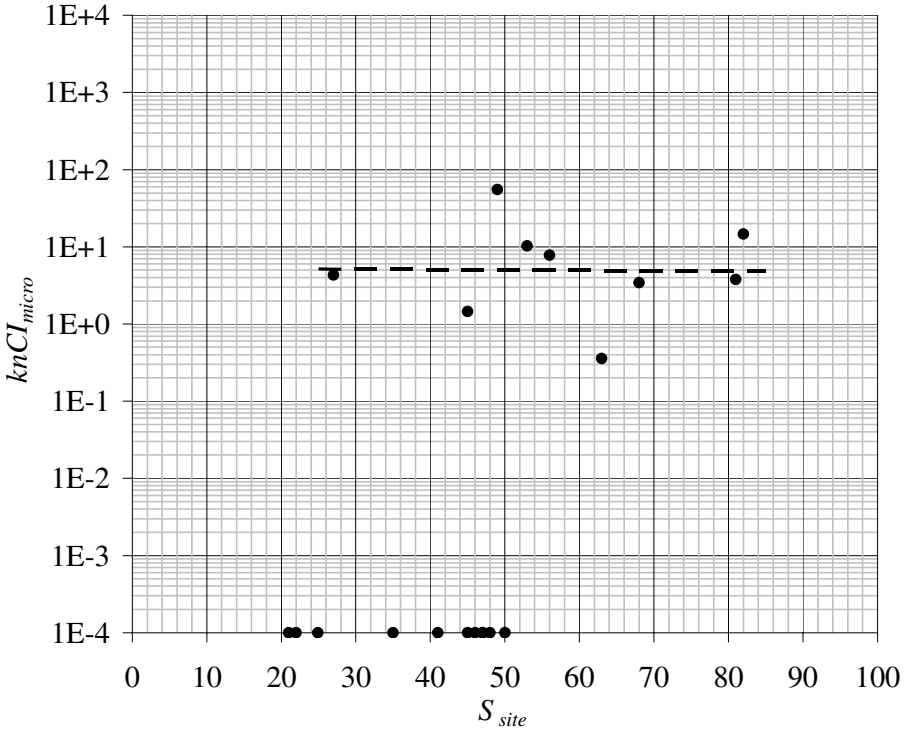

Figure 6-5 *knCI$_{micro}$* vs. *S$_{site}$*

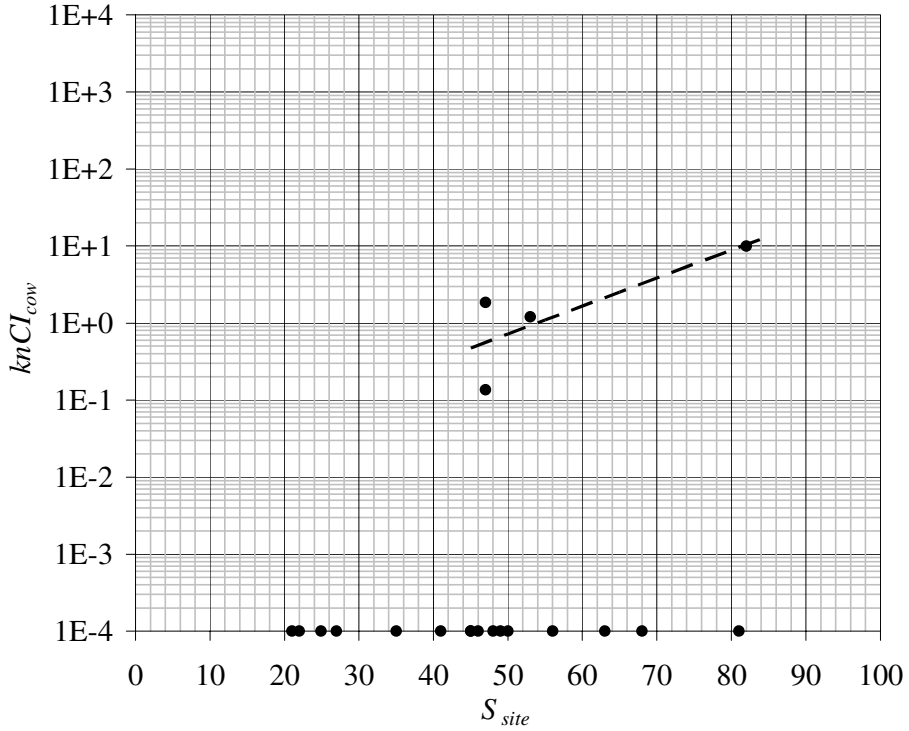

Figure 6-6 $knCI_{cow}$ vs. S_{site}

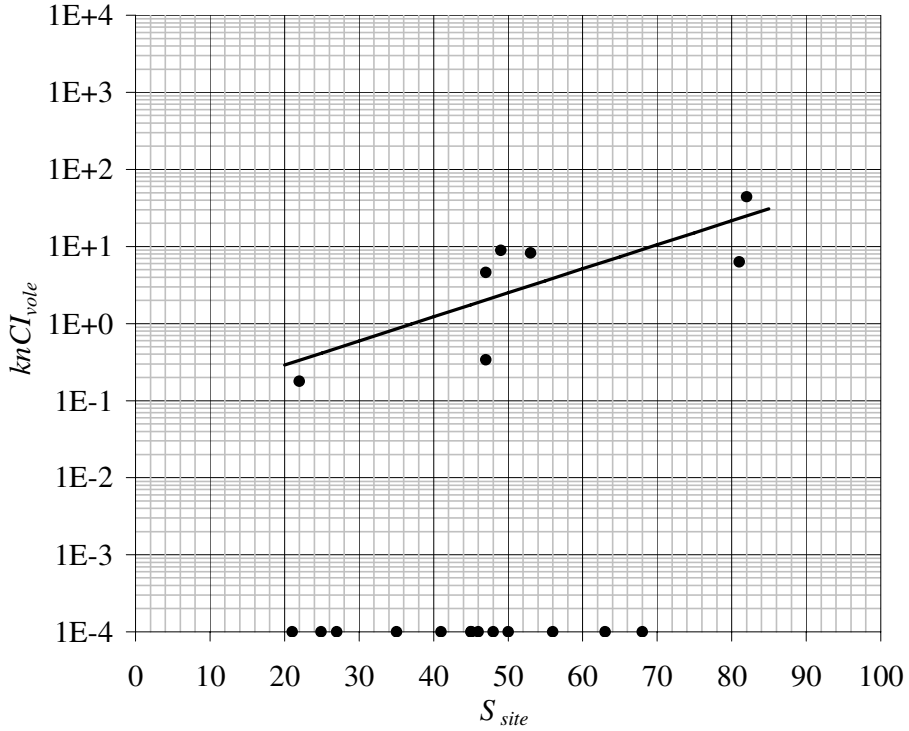

Figure 6-7 $knCI_{vole}$ vs. S_{site}

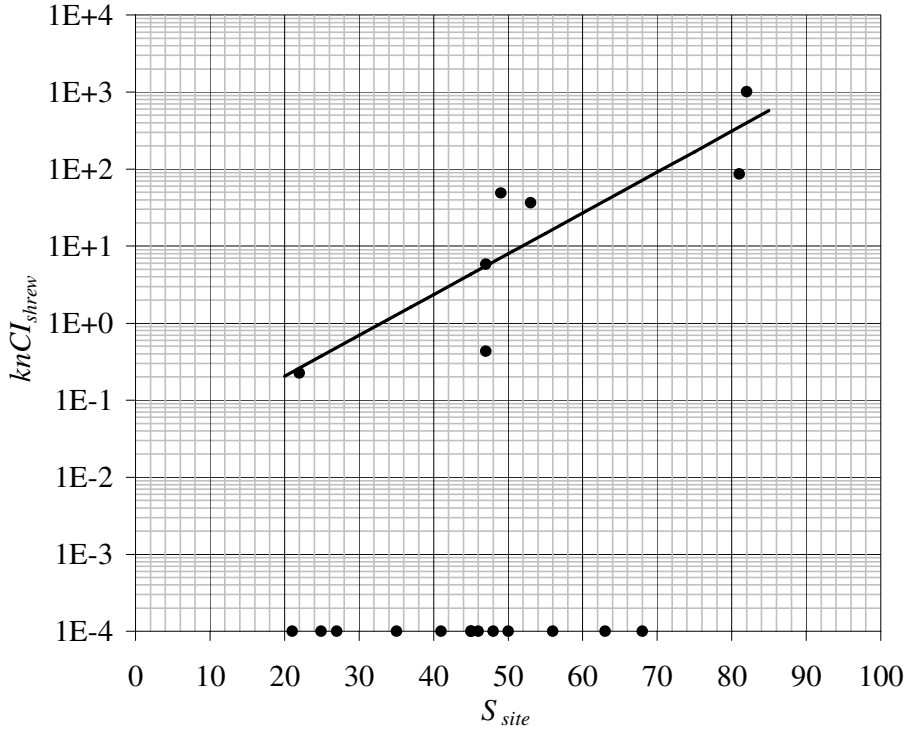

Figure 6-8 *knCI*$_{shrew}$ vs. *S*$_{site}$

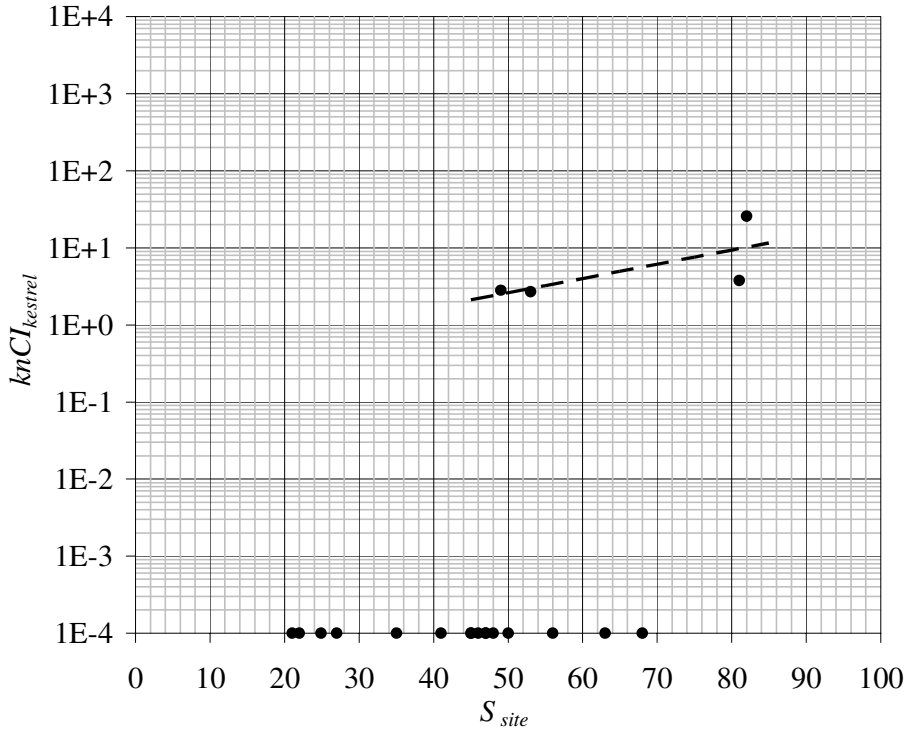

Figure 6-9 *knCI*$_{kestrel}$ vs. *S*$_{site}$

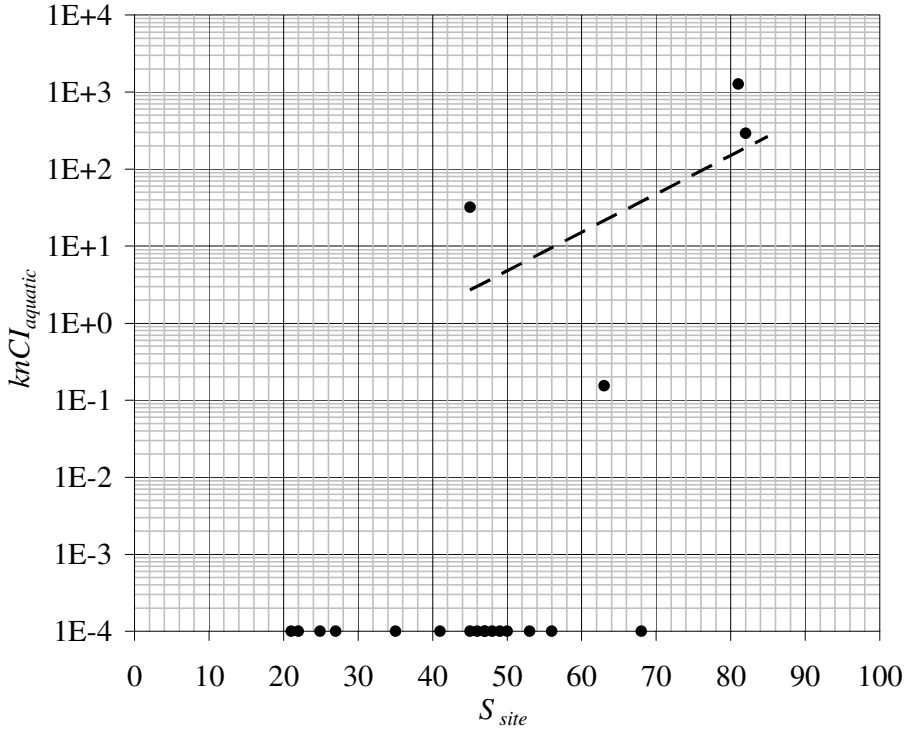

Figure 6-10 $knCI_{aquatic}$ vs. S_{site}

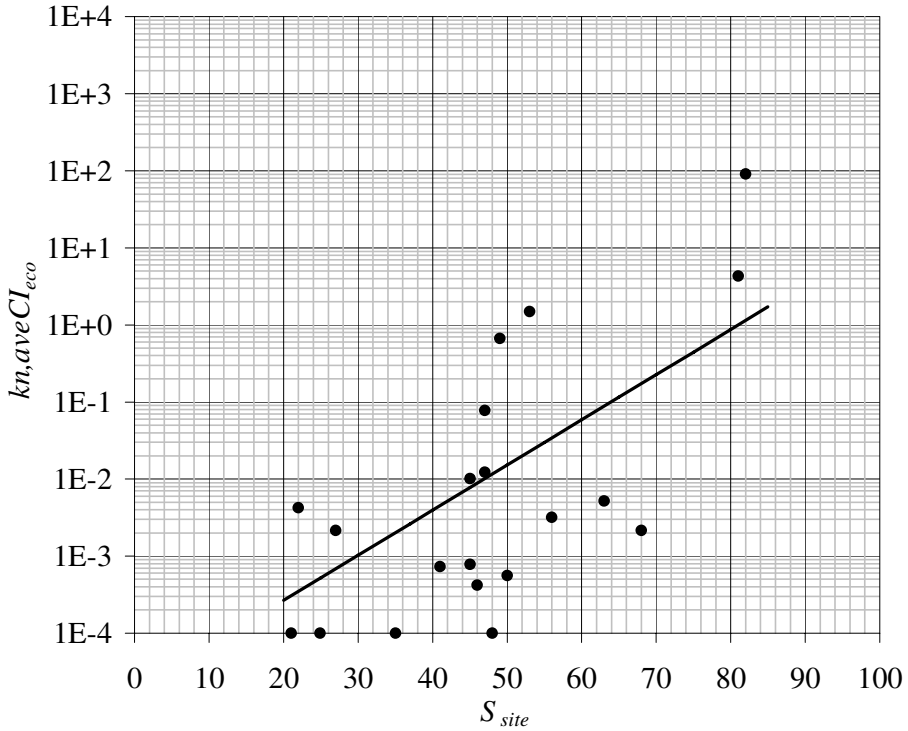

Figure 6-11 $kn,aveCI_{eco}$ vs. S_{site}

6.4.2 Potential Scenario

Similarly, Figure 6-12 to Figure 6-20 are a series of semi-log plots relating the cumulative hazard indices to NCSCS scores under the potential scenario. The reasons for the outliers and the process of establishing acceptable correlation are the same as stated before. Compared to the known scenario, humans, cows, and aquatic life are the additional receptors with correlated $poCI_k$ values. Table 6-4 summarises the correlation statistics.

Table 6-4 $poCI_k$ vs. S_{site} correlation statistics

$poCI_k$	r_p	n	t	t_a	Correlation acceptable?
$poCI_{human}$	0.76	19	4.75	1.74	Yes
$poCI_{plant}$	0.34	16	1.36	1.76	No
$poCI_{micro}$	-0.01	9	-0.01	-1.89	No
$poCI_{cow}$	0.72	7	2.33	2.02	Yes
$poCI_{vole}$	0.51	9	1.55	1.89	No
$poCI_{shrew}$	0.64	9	2.19	1.89	Yes
$poCI_{kestrel}$	0.68	5	1.63	2.35	No
$poCI_{aquatic}$	0.66	9	2.34	1.89	Yes
$po,aveCI_{eco}$	0.72	18	4.12	1.75	Yes

The regression equations below relate receptor $poCI_k$ values with S_{site} under this scenario. The equations represent a band of probable results having prediction intervals ranging from 3 to 4 orders of magnitude.

Equation 6-5 $\log(poCI_{human}) = [0.067S_{site} - 0.85] \pm 1.5; \quad 20 < S_{site} < 85$

Equation 6-6 $\log(poCI_{cow}) = [0.054S_{site} - 2.4] \pm 1.5; \quad 20 < S_{site} < 85$

Equation 6-7 $\log(poCI_{vole}) = [0.038S_{site} - 1.9] \pm 1.5; \quad 20 < S_{site} < 85$

Equation 6-8 $\log(poCI_{shrew}) = [0.062S_{site} - 2.6] \pm 1.5; \quad 20 < S_{site} < 85$

Equation 6-9 $\log(poCI_{aquatic}) = [0.053S_{site} - 0.86] \pm 1.5; \quad 40 < S_{site} < 85$

Equation 6-10 $\log(po, aveCI_{eco}) = [0.080S_{site} - 5.4] \pm 2; \quad 20 < S_{site} < 85$

As before, approximate 90% prediction intervals for cumulative hazard indices at the NCSCS class cut off values of 37, 50, and 70 were estimated as summarised in the table below. Ecological receptors have $poCI_k$ intervals at the Class N cut off value that straddle 1, suggesting the NCSCS is accurately calibrated at this cut off value for these receptors. However, the lower prediction limit for $poCI_{human}$ is at 1 meaning some adjustment to the NCSCS is needed to calibrate scores to risk assessment results. In general, $poCI_k$ values at the Class 1 cut off score are approximately 1 to 2 orders of magnitude greater than those at the Class N cut off value, similar to the known scenario.

Table 6-5 $poCI_k$ prediction intervals at NCSCS class cut off scores

Receptor or Receptor Group	NCSCS Class Cut Off Scores								
	Class N to 3: 37			Class 3 to 2: 50			Class 2 to 1: 70		
	LPL	Mid	UPL	LPL	Mid	UPL	LPL	Mid	UPL
Human	1	40	1,000	10	300	1×10^{4}	200	7,000	2×10^{5}
Plants & Invert.	-	-	-	-	-	-	-	-	-
Microorganisms	-	-	-	-	-	-	-	-	-
Cow	0.01	0.5	10	0.07	2	70	0.9	30	900
Meadow Vole	0.01	0.3	10	0.03	1	30	0.2	5	200
Masked Shrew	0.01	0.5	10	0.09	3	90	2	50	2,000
American Kestrel	-	-	-	-	-	-	-	-	-
Aquatic Life	0.4	10	400	2	60	2,000	20	700	2×10^{4}
Average Ecological	$<10^{-4}$	0.004	0.4	4×10^{-4}	0.04	4	0.02	2	200

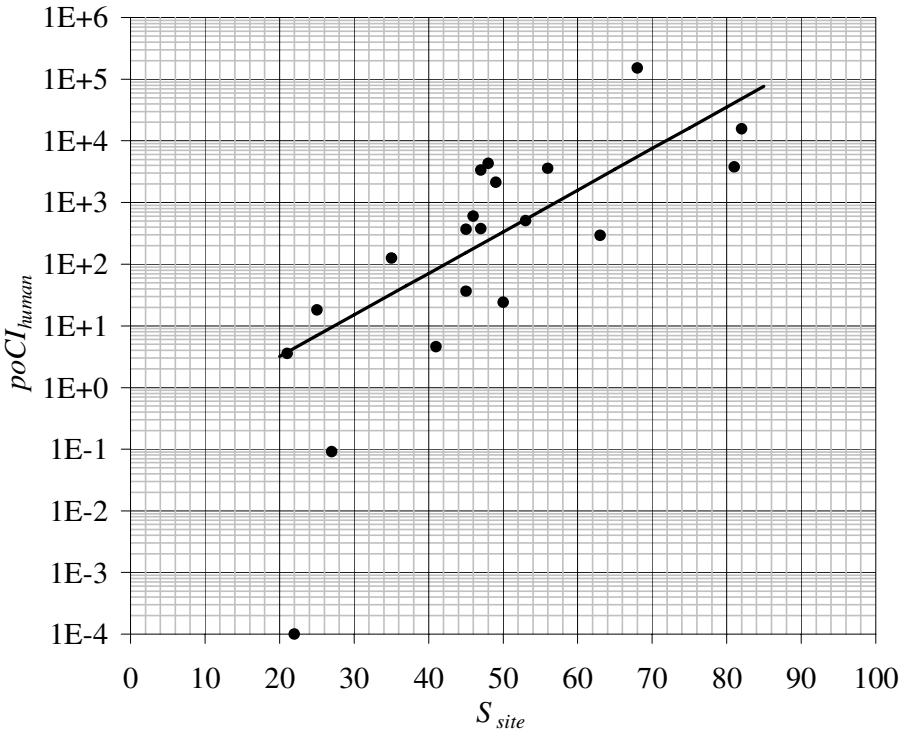

Figure 6-12 $poCI_{human}$ vs. S_{site}

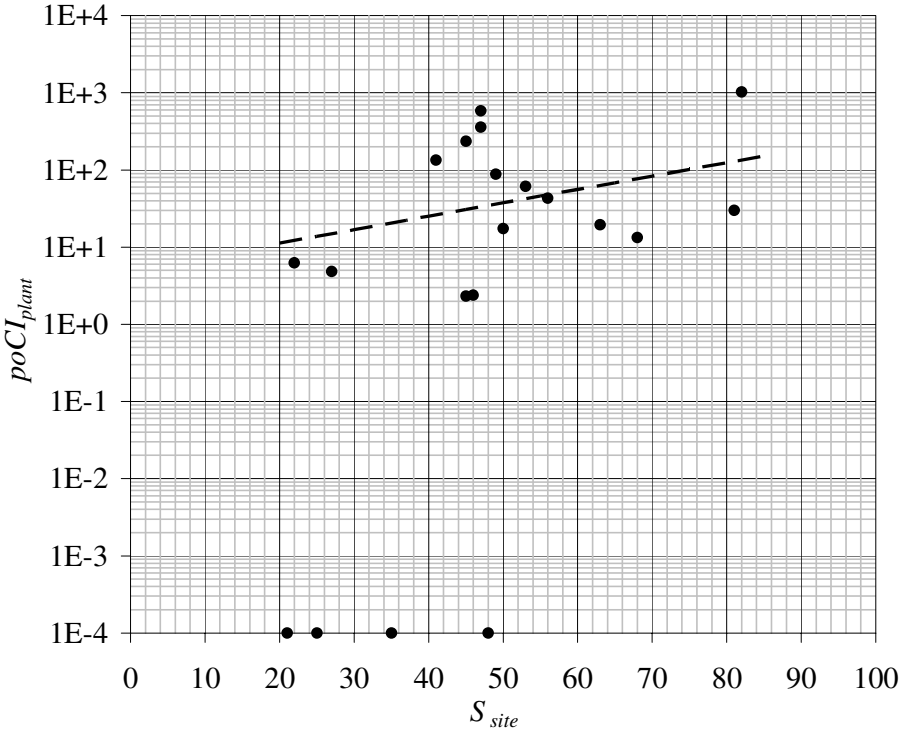

Figure 6-13 $poCI_{plant}$ vs. S_{site}

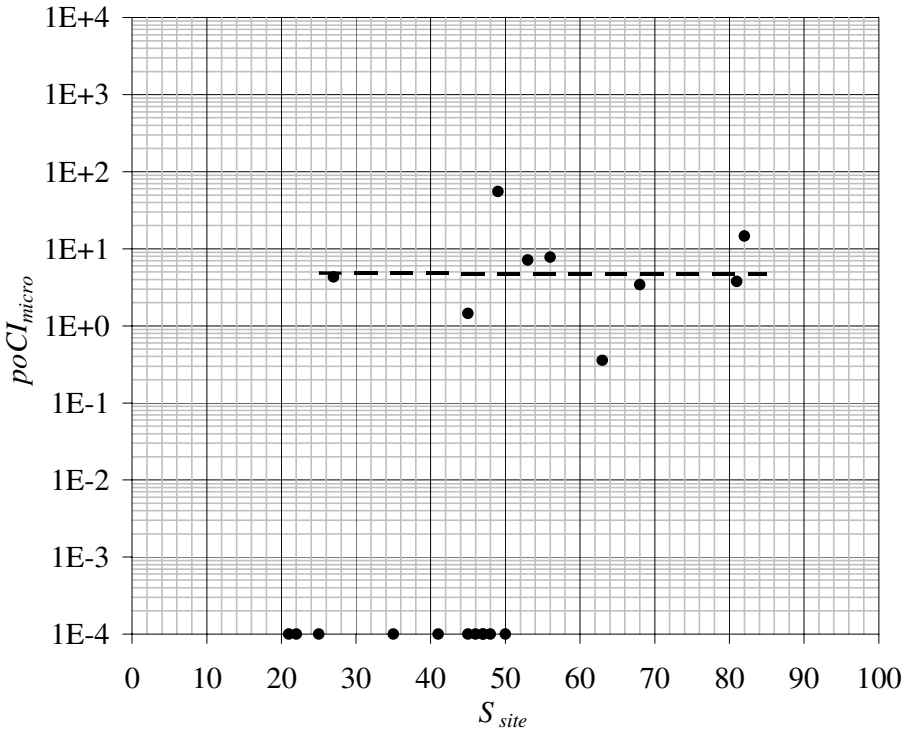

Figure 6-14 $poCI_{micro}$ vs. S_{site}

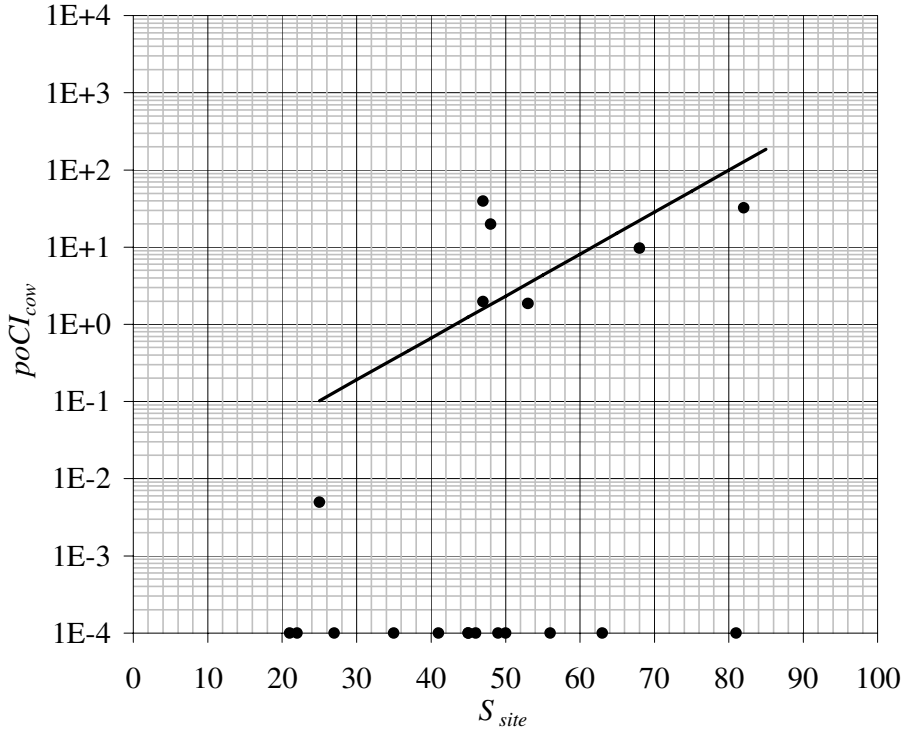

Figure 6-15 $poCI_{cow}$ vs. S_{site}

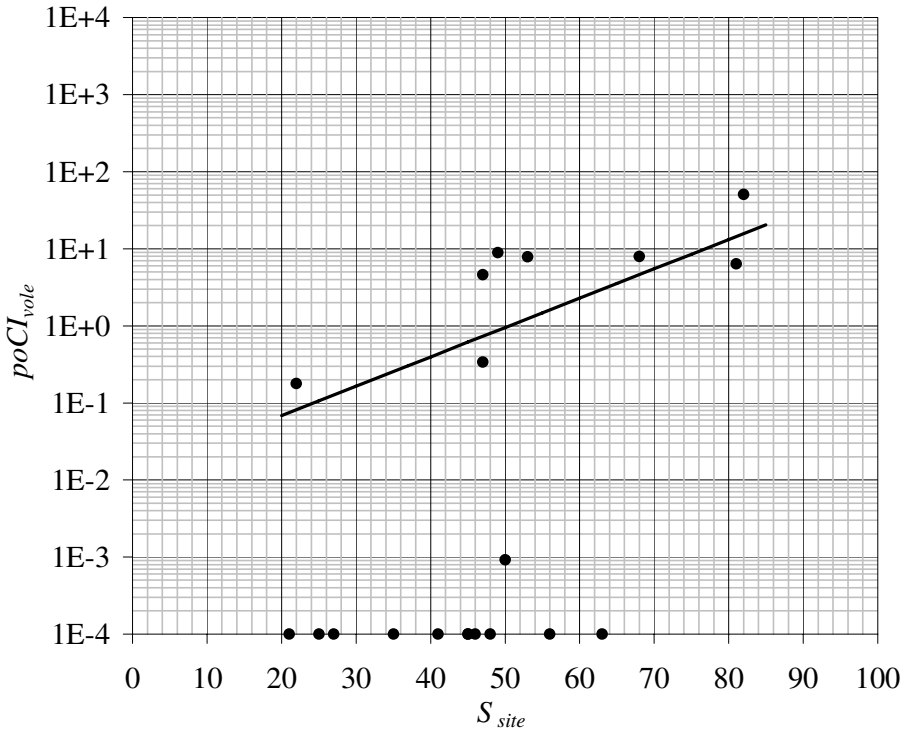

Figure 6-16 $poCI_{vole}$ vs. S_{site}

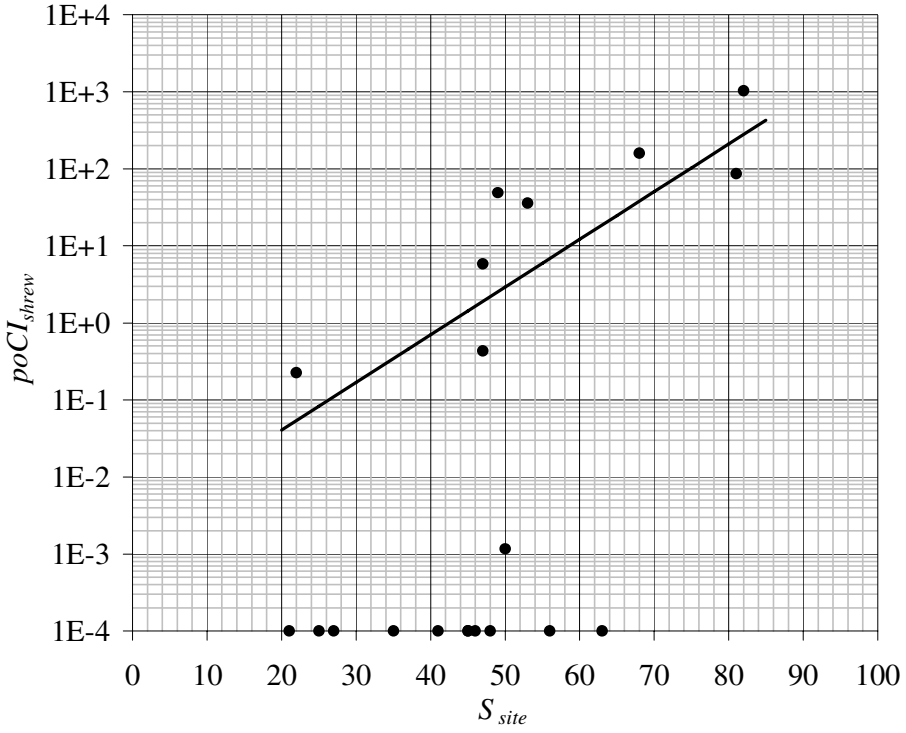

Figure 6-17 $poCI_{shrew}$ vs. S_{site}

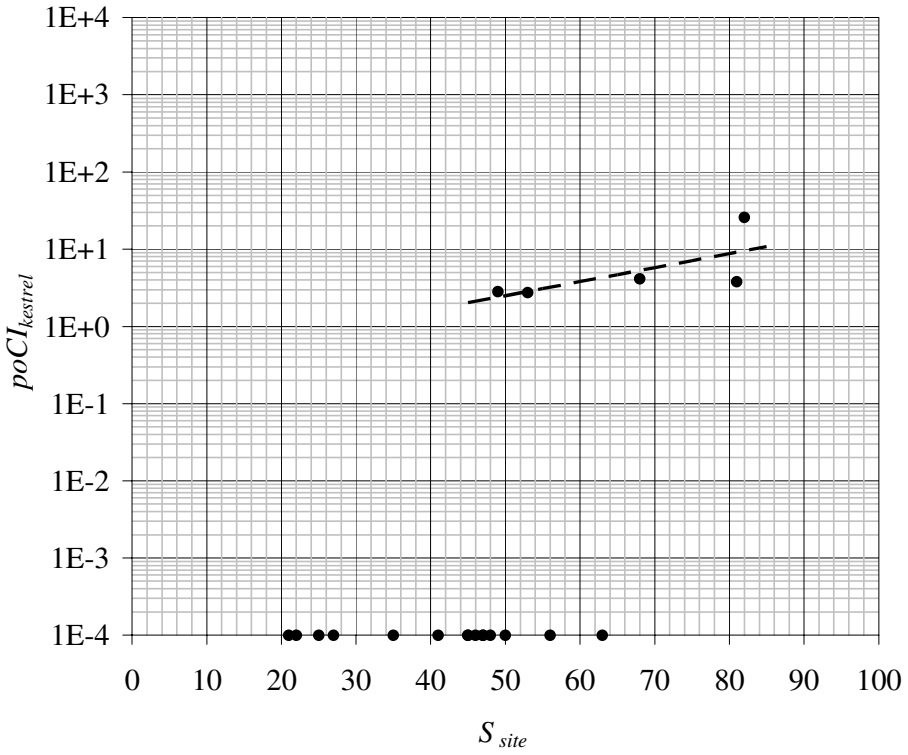

Figure 6-18 *poCI*$_{kestrel}$ vs. *S*$_{site}$

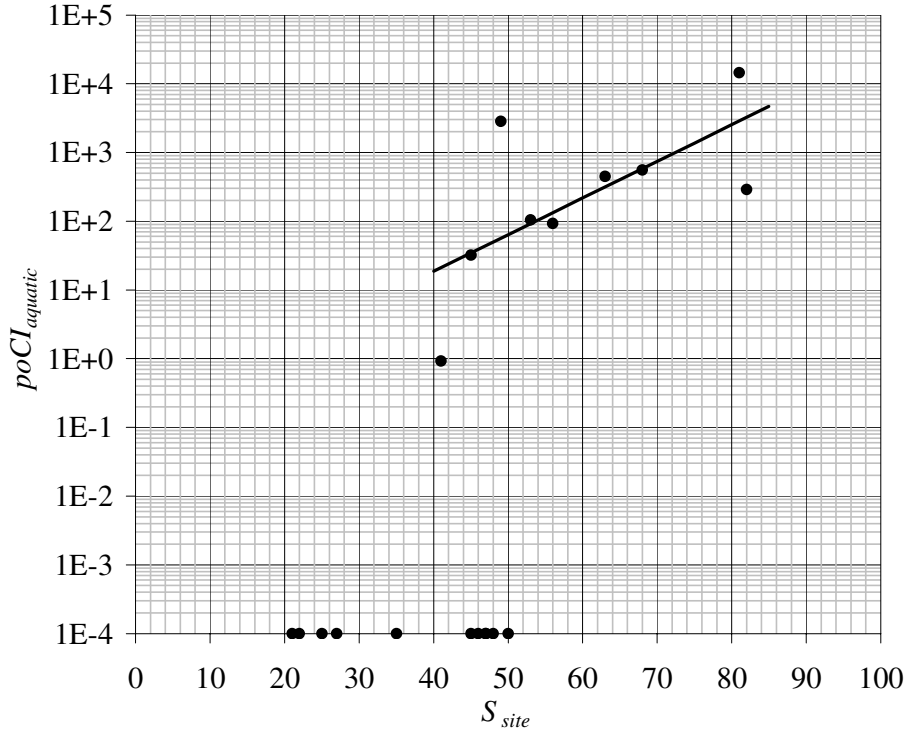

Figure 6-19 *poCI*$_{aquatic}$ vs. *S*$_{site}$

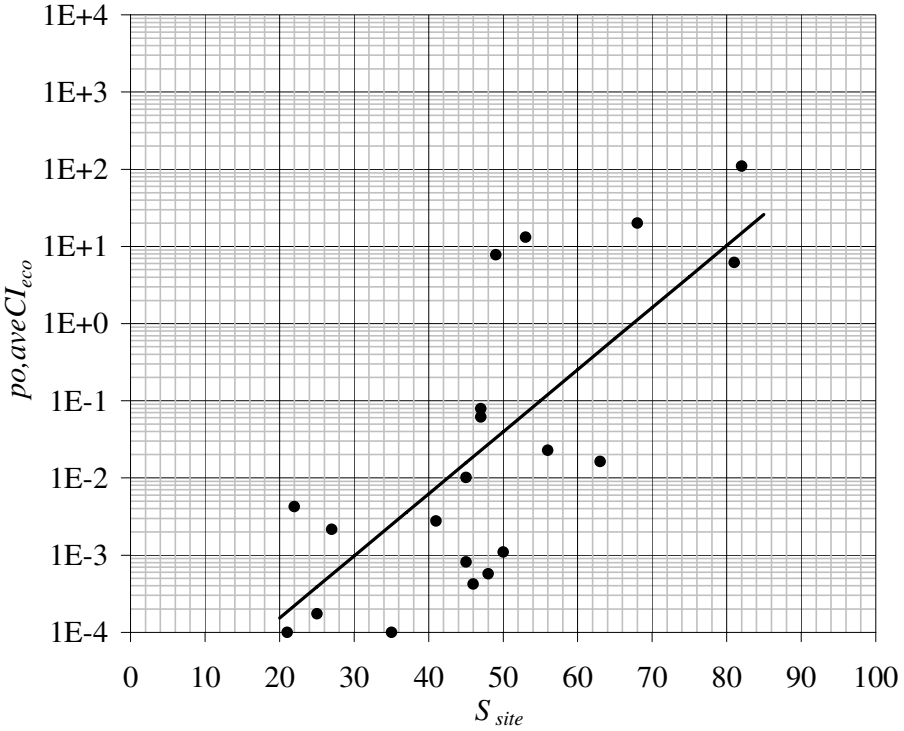

Figure 6-20 *po,aveCI*$_{eco}$ vs. S_{site}

6.4.3 NCSCS Modifications

The significant data scatter in the figures above suggests an opportunity to modify the NCSCS to be more closely aligned with PQRA results. Optimal site characteristic category weighting factors, *w*, were sought for each receptor or receptor group and scenario. Optimal weighting factors were determined using the OptQuest module in Oracle® Crystal Ball (2009) with the objective being to maximise the Pearson product moment correlation coefficients, r_p, between CI_k values and modified NCSCS scores, $modS_{site}$, calculated using the equation below.

Equation 6-11 $$modS_{site} = w_{con}S_{con} + w_{mig}S_{mig} + w_{exp}S_{exp}$$

The optimal weighting factors are summarised in the table below. An interesting observation is that some categories are not required to optimise S_{site}, depending on the receptor and scenario.

Table 6-6 Optimal category weighting factors

Receptor or Receptor Group	Scenario & Weighting Factors					
	Known			Potential		
	w_{con}	w_{mig}	w_{exp}	w_{con}	w_{mig}	w_{exp}
Human	1.06	0	1.94	2.76	0.24	0
Plants & Invert.	0	0.05	2.95	0	0.18	2.82
Microorganisms	0	0.05	2.95	0	0.05	2.95
Cow	1.45	0.39	1.16	0	0	3.00
Meadow Vole	2.61	0.16	0.23	2.86	0.04	0.10
Masked Shrew	2.61	0.16	0.23	2.86	0.04	0.10
American Kestrel	0.20	2.75	0.05	0	1.68	1.32
Aquatic Life	0.51	0	2.49	2.70	0.26	0.04
Average Ecological	1.98	0	1.02	1.41	1.44	0.15

The following figures are a series of plots relating cumulative hazard indices, under known and potential scenarios, to modified NCSCS site scores using the weighting factors in Table 6-6. Figure 6-21 to Figure 6-25 show the relationship of $knCI_k$ values for humans, plants, meadow voles, masked shrews, and the average for all ecological receptors to $modS_{site}$. Figure 6-21, for human receptors, is not obviously different from Figure 6-3 but site scores are modified enough to generate a statistically significant, positive correlation. Figure 6-22, for plants & soil invertebrates, is noticeably different from Figure 6-4 and shows four vertical data point columns. This occurred because $modS_{site}$ values are dominated by weighted S_{exp} scores, which can be one of four values. The data in Figure 6-23 for voles and Figure 6-24 for shrews is more evenly spaced across the range of possible $modS_{site}$ values compared to the data in Figure 6-7 and Figure 6-8, respectively. Significant differences are not obvious when comparing data in Figure

6-25 for $kn,aveCI_{eco}$ to Figure 6-11. Positive correlations of $knCI_k$ values for microorganisms, cows, American kestrels, and aquatic life were not clear and thus not presented. Table 6-7 summarises the associated correlation statistics.

Table 6-7 $knCI_k$ vs. $modS_{site}$ correlation statistics

$knCI_k$	r_p	n	t	t_a	Correlation acceptable?
$knCI_{human}$	0.48	17	2.09	1.75	Yes
$knCI_{plant}$	0.50	16	2.19	1.76	Yes
$knCI_{micro}$	0.15	9	0.41	1.89	No
$knCI_{cow}$	0.80	4	1.88	2.92	No
$knCI_{vole}$	0.80	7	2.96	2.02	Yes
$knCI_{shrew}$	0.88	7	4.10	2.02	Yes
$knCI_{kestrel}$	0.78	4	1.79	2.92	No
$knCI_{aquatic}$	0.83	4	2.08	2.92	No
$kn,aveCI_{eco}$	0.62	16	2.99	1.76	Yes

The following regression equations relate receptor $knCI_k$ values with $modS_{site}$ under the known scenario. The equations represent a band of probable results having prediction intervals ranging from 2 to 4 orders of magnitude, a similar interval to before NCSCS site scores were modified.

Equation 6-12 $\log(knCI_{human}) = [0.041 modS_{site} - 0.95] \pm 2; \quad 20 < modS_{site} < 80$

Equation 6-13 $\log(knCI_{plant}) = [0.030 modS_{site} - 0.18] \pm 1.5; \quad 25 < modS_{site} < 80$

Equation 6-14 $\log(knCI_{vole}) = [0.029 modS_{site} - 1.1] \pm 1; \quad 20 < modS_{site} < 90$

Equation 6-15 $\log(knCI_{shrew}) = [0.049 modS_{site} - 1.6] \pm 1; \quad 20 < modS_{site} < 90$

Equation 6-16 $\log(kn, aveCI_{eco}) = [0.062 modS_{site} - 5.0] \pm 2; \quad 20 < modS_{site} < 85$

The $knCI_{vole}$ and $knCI_{shrew}$ intervals at the NCSCS Class cut off values are similar to those before modification. The modification improved correlations of some other

$knCI_k$ values, allowing additional cut off intervals to be estimated. With the exception of average ecological receptor values, the remaining equations predict $knCI_k$ values ranging from 0.9 to 9 at the Class N cut off value and approximately 1 order of magnitude greater at the Class 1 cut off value.

Table 6-8 $knCI_k$ prediction intervals at NCSCS class cut off scores using $modS_{site}$ values

Receptor or Receptor Group	NCSCS Class Cut Off Scores								
	Class N to 3: 37			Class 3 to 2: 50			Class 2 to 1: 70		
	LPL	Mid	UPL	LPL	Mid	UPL	LPL	Mid	UPL
Human	0.04	4	400	0.1	10	1,000	0.8	80	8,000
Plants & Invert.	0.3	9	300	0.7	20	700	3	90	3,000
Microorganisms	-	-	-	-	-	-	-	-	-
Cow	-	-	-	-	-	-	-	-	-
Meadow Vole	0.09	0.9	9	0.2	2	20	0.8	8	80
Masked Shrew	0.2	2	20	0.7	7	70	6	60	600
American Kestrel	-	-	-	-	-	-	-	-	-
Aquatic Life	-	-	-	-	-	-	-	-	-
Average Ecological	$<10^{-4}$	0.002	0.2	1×10^{-4}	0.01	1	0.002	0.2	20

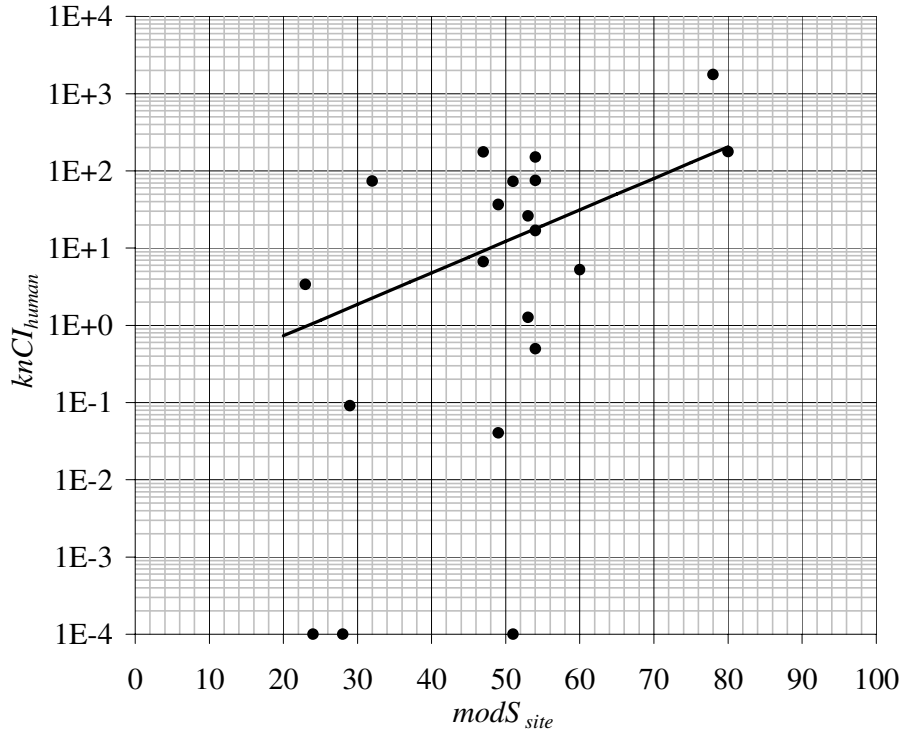

Figure 6-21 *knCI*$_{human}$ vs. *modS*$_{site}$

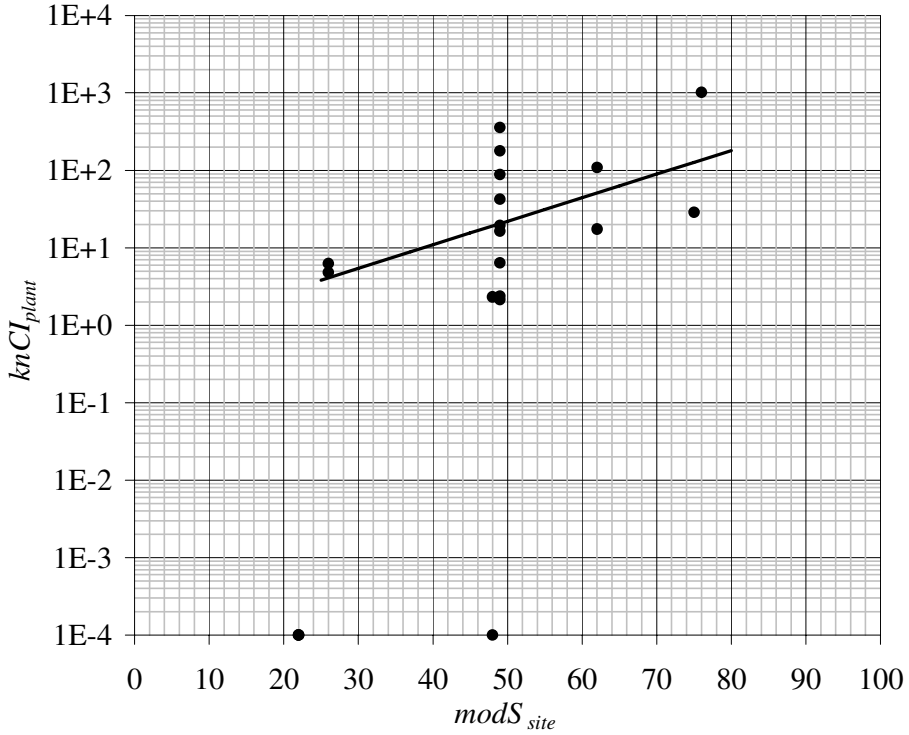

Figure 6-22 *knCI*$_{plant}$ vs. *modS*$_{site}$

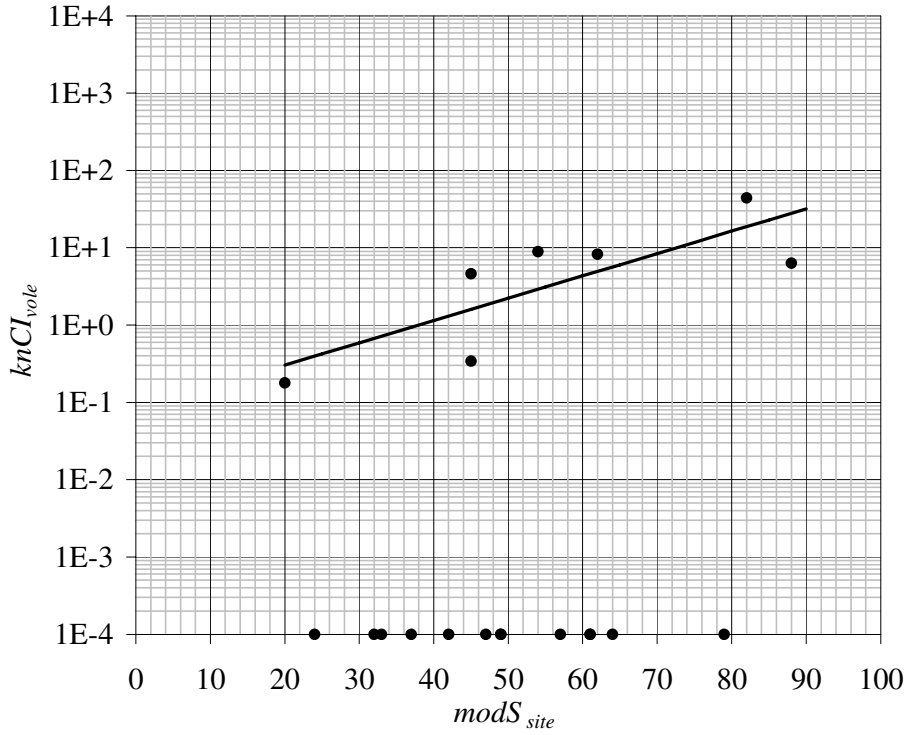

Figure 6-23 *knCI$_{vole}$* vs. *modS$_{site}$*

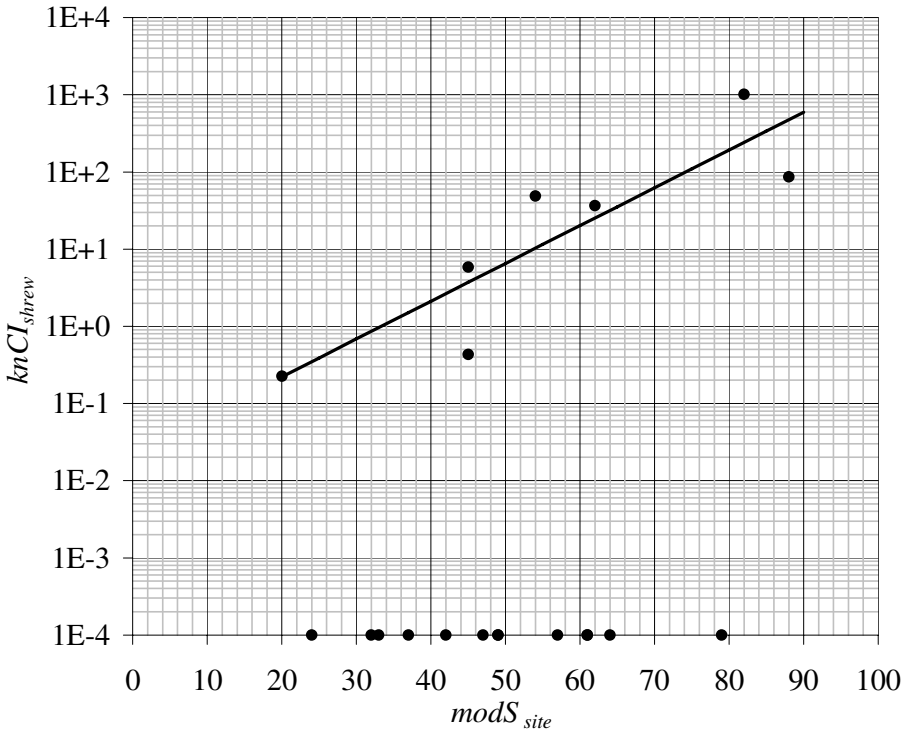

Figure 6-24 *knCI$_{shrew}$* vs. *modS$_{site}$*

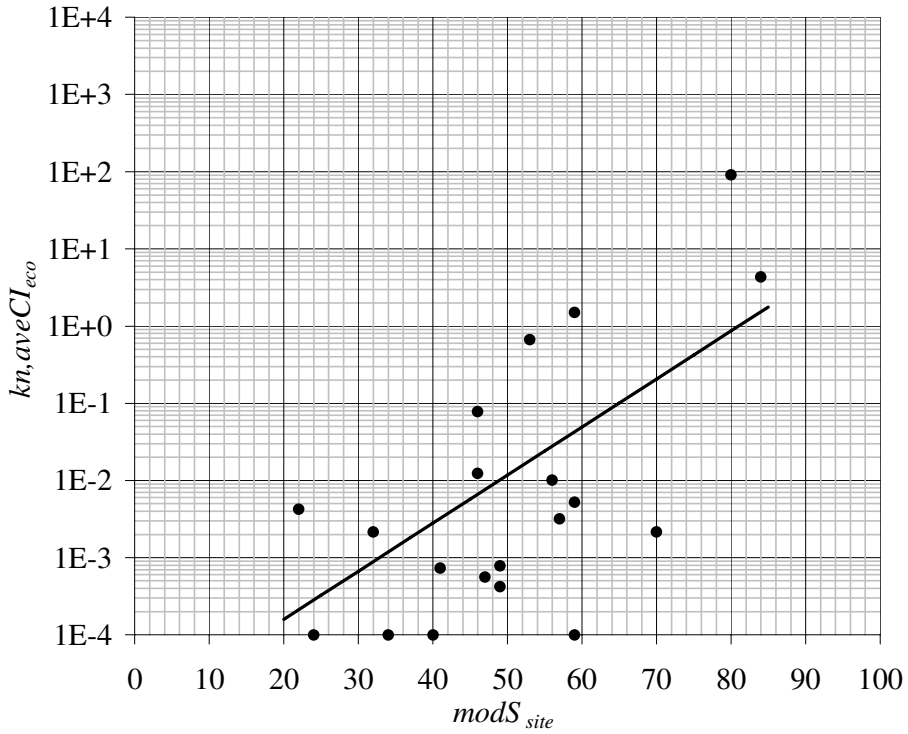

Figure 6-25 *kn,aveCI*$_{eco}$ vs. *modS*$_{site}$

Figure 6-26 to Figure 6-32 show the relationships of $poCI_k$ values for humans, plants, cows, voles, shrews, aquatic life, and the average *CI* of all ecological receptors to $modS_{site}$. Comparing Figure 6-26 to Figure 6-12 shows an improved correlation for $poCI_{human}$ values. An acceptable correlation now exists for $poCI_{plant}$ values although the data is grouped in four clusters for the reason described previously. The $poCI_{cow}$ values are also clustered for the same reason. The data scatter in the remaining plots is not significantly different than before NCSCS scores were modified. Table 6-9 summarises the correlation statistics for all receptors.

Table 6-9 $poCI_k$ vs. $modS_{site}$ correlation statistics

$poCI_k$	r_p	n	t	t_a	Correlation acceptable?
$poCI_{human}$	0.82	19	5.91	1.74	Yes
$poCI_{plant}$	0.47	16	1.97	1.76	Yes
$poCI_{micro}$	0.16	9	0.44	1.89	No
$poCI_{cow}$	0.82	7	3.19	2.02	Yes
$poCI_{vole}$	0.65	9	2.25	1.89	Yes
$poCI_{shrew}$	0.77	9	3.18	1.89	Yes
$poCI_{kestrel}$	0.77	5	2.09	2.35	No
$poCI_{aquatic}$	0.78	9	3.26	1.89	Yes
$po,aveCI_{eco}$	0.74	18	4.36	1.75	Yes

The following equations predict $poCI_k$ intervals based on the figures below:

Equation 6-17 $\log(poCI_{human}) = [0.068 modS_{site} - 1.2] \pm 1.5; \quad 20 < modS_{site} < 90$

Equation 6-18 $\log(poCI_{plant}) = [0.029 modS_{site} + 0.15] \pm 1.5; \quad 25 < modS_{site} < 80$

Equation 6-19 $\log(poCI_{cow}) = [0.073 modS_{site} - 3.0] \pm 1; \quad 20 < modS_{site} < 75$

Equation 6-20 $\log(poCI_{vole}) = [0.040 modS_{site} - 2.1] \pm 1; \quad 20 < modS_{site} < 90$

Equation 6-21 $\log(poCI_{shrew}) = [0.062 modS_{site} - 2.8] \pm 1.5; \quad 20 < modS_{site} < 90$

Equation 6-22 $\log(poCI_{aquatic}) = [0.053 modS_{site} - 1.0] \pm 1; \quad 30 < modS_{site} < 90$

Equation 6-23 $\log(po,aveCI_{eco}) = [0.073 modS_{site} - 5.1] \pm 2; \quad 20 < modS_{site} < 85$

Referring to Table 6-10, the predicted $poCI_k$ intervals for humans, shrews, and average ecological cumulative hazard indices at the NCSCS class cut off values are similar to those estimated for unmodified S_{site} values. Compared to the $poCI_k$ intervals for unmodified S_{site} values, the prediction intervals for plants & soil invertebrates, cows, meadow voles, masked shrew, and aquatic life have improved, being narrower. At the NCSCS Class N cut off value, the equations above predict $poCI_k$ values in the range of

0.1 to 10 and values roughly 1 to 2 orders of magnitude greater at the Class 1 cut off value, as before.

Table 6-10 $poCI_k$ prediction intervals at NCSCS class cut off scores using $modS_{site}$ values

Receptor or Receptor Group	NCSCS Class Cut Off Scores								
	Class N to 3: 37			Class 3 to 2: 50			Class 2 to 1: 70		
	LPL	Mid	UPL	LPL	Mid	UPL	LPL	Mid	UPL
Human	0.7	20	700	5	200	5,000	100	4,000	1×10^{5}
Plants & Invert.	0.5	20	500	1	40	1,000	4	100	4,000
Microorganisms	-	-	-	-	-	-	-	-	-
Cow	0.05	0.5	5	0.4	4	40	10	100	1,000
Meadow Vole	0.02	0.2	2	0.08	0.8	8	0.5	5	50
Masked Shrew	0.01	0.3	10	0.07	2	70	1	40	1,000
American Kestrel	-	-	-	-	-	-	-	-	-
Aquatic Life	0.8	8	80	4	40	400	40	400	4,000
Average Ecological	$<10^{-4}$	0.004	0.4	4×10^{-4}	0.04	4	0.01	1	100

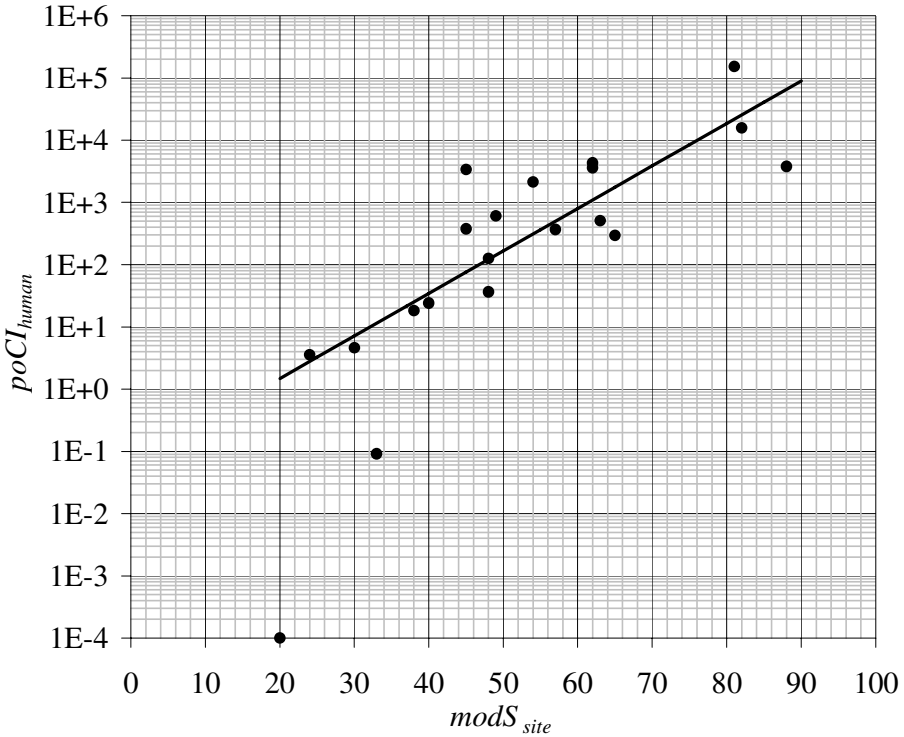

Figure 6-26 $poCI_{human}$ vs. $modS_{site}$

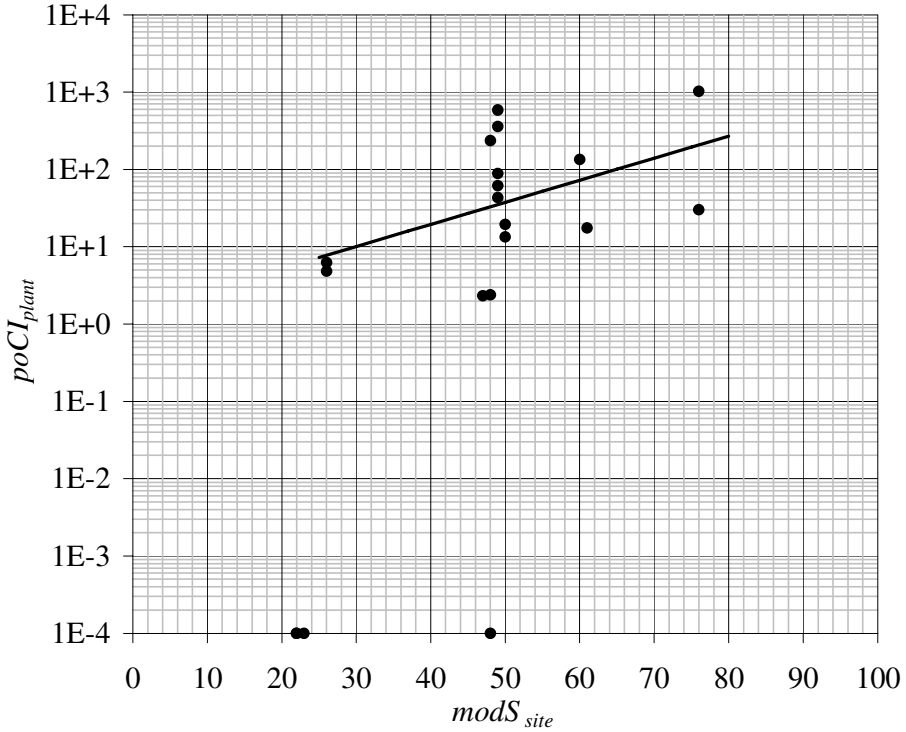

Figure 6-27 *poCI*$_{plant}$ vs. *modS*$_{site}$

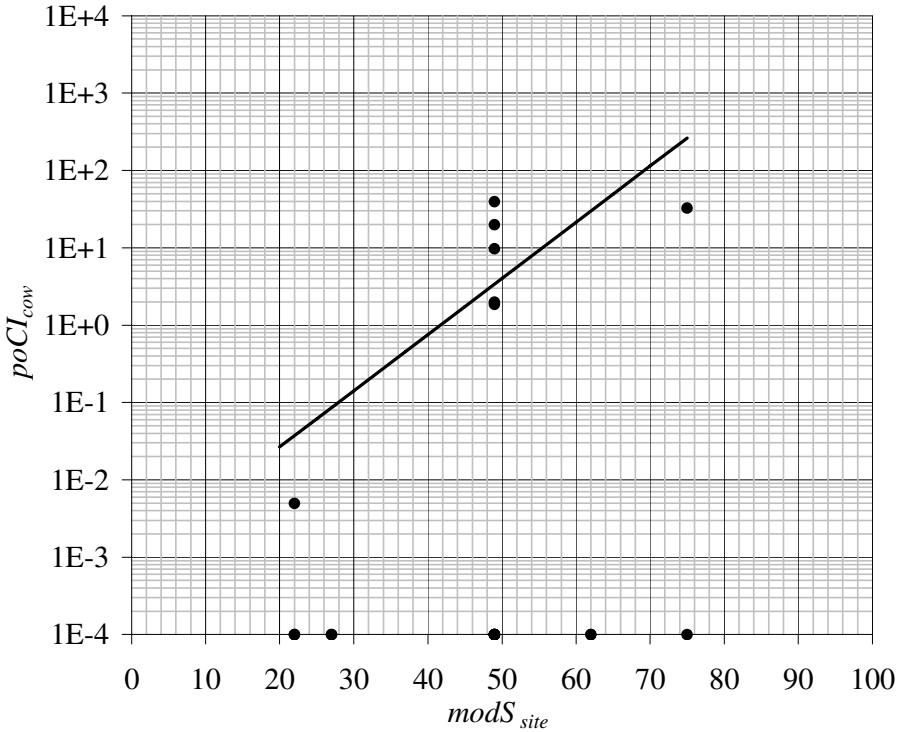

Figure 6-28 *poCI*$_{cow}$ vs. *modS*$_{site}$

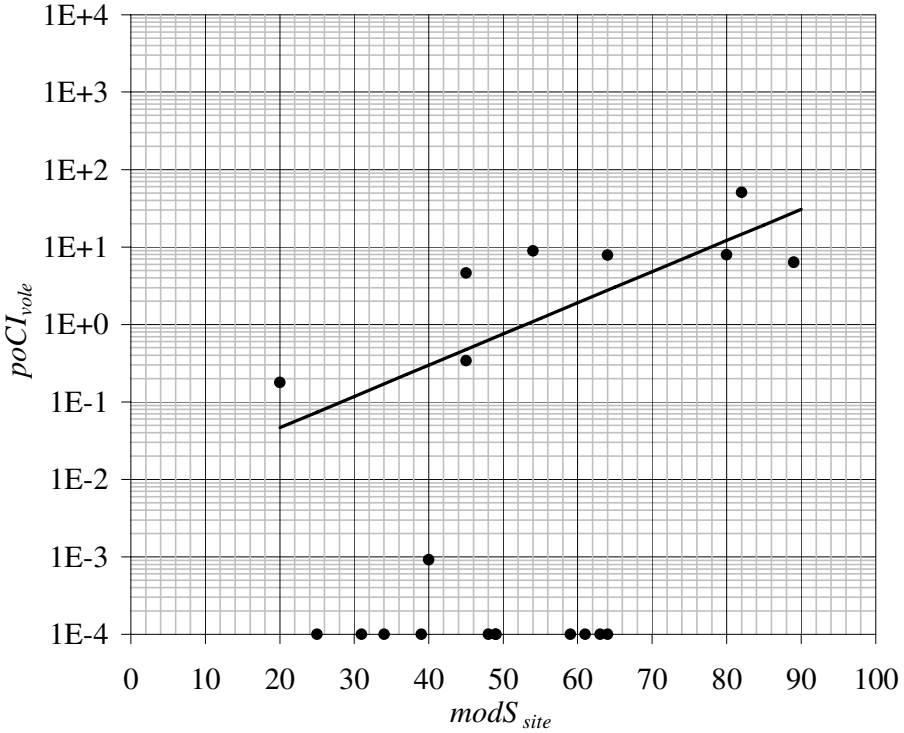

Figure 6-29 *poCI*$_{vole}$ vs. *modS*$_{site}$

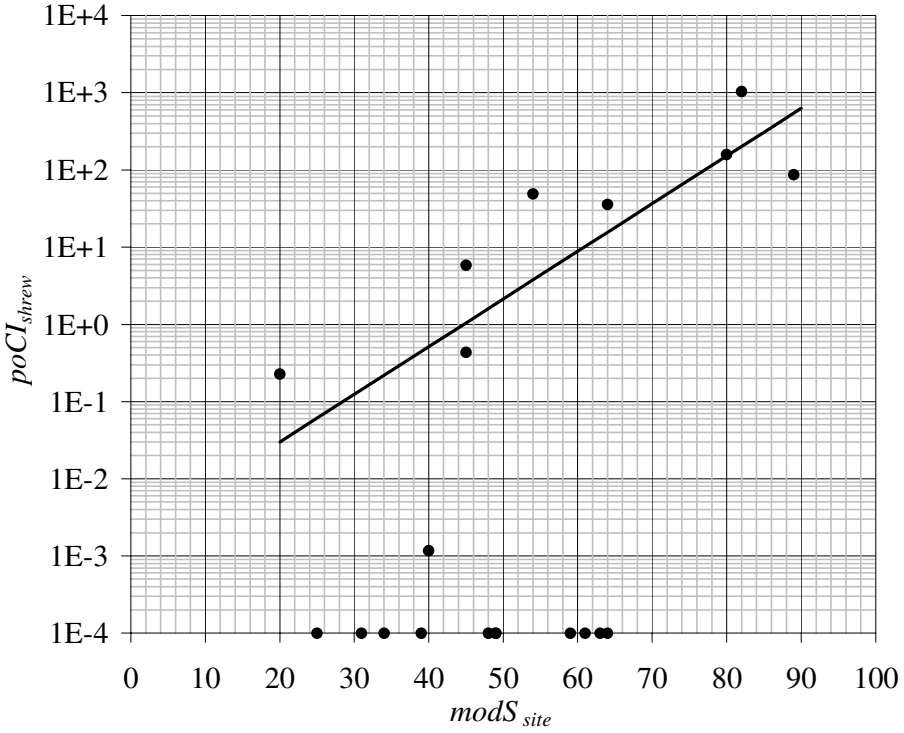

Figure 6-30 *poCI*$_{shrew}$ vs. *modS*$_{site}$

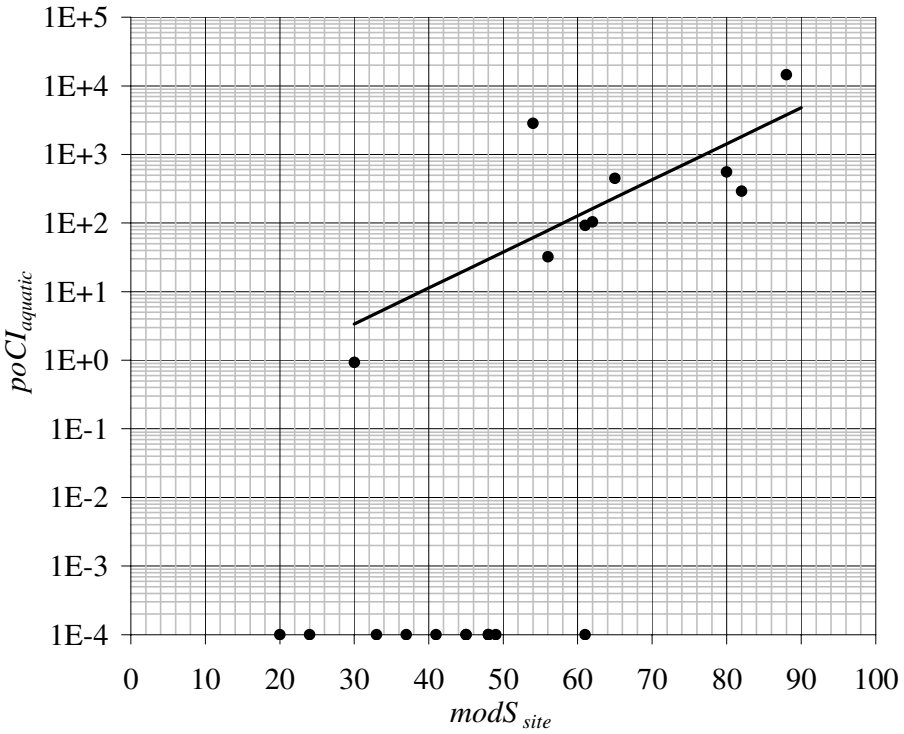

Figure 6-31 *poCI*$_{aquatic}$ vs. *modS*$_{site}$

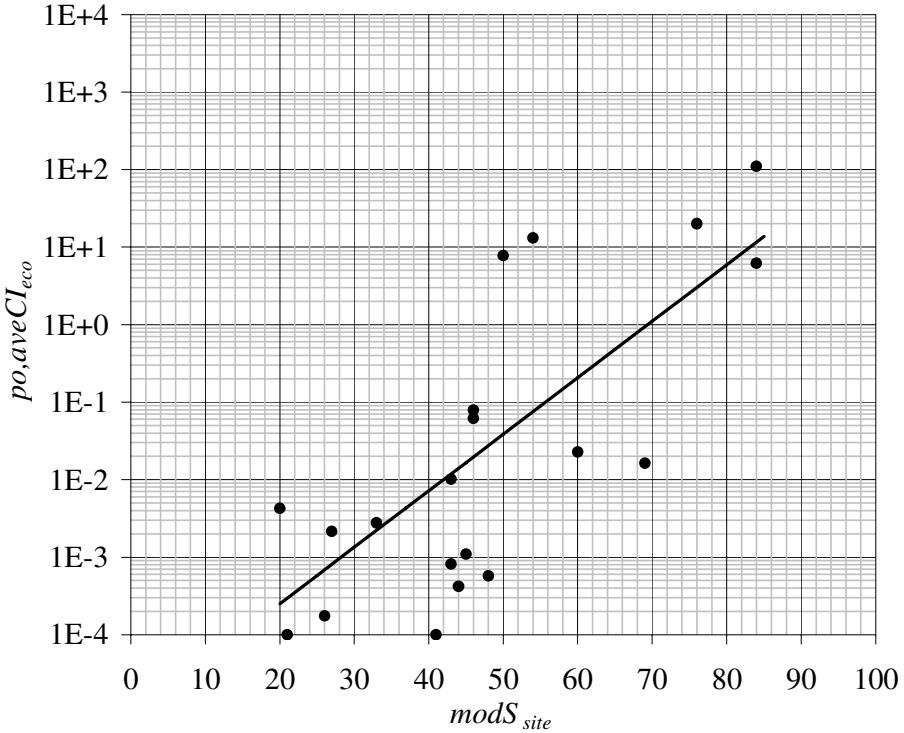

Figure 6-32 *po,aveCI*$_{eco}$ vs. *modS*$_{site}$

6.5 Conclusions

Based on the results, three conclusions can be made. First, NCSCS site scores are positively correlated with the cumulative hazard indices for some biological receptors. Under the defined known scenario for the PQRAs, equations relating cumulative hazard indices for meadow voles, masked shrews, as well as the average cumulative hazard indices for all 7 ecological receptors to NCSCS site scores have been proposed. Similarly for the potential scenario, equations have been developed for the same receptors plus humans, cows, and aquatic life. The equations can be used to estimate contaminated site hazard ranges for specified receptors or receptor groups given an NCSCS site score.

Second, receptor and scenario specific weighting factors have been determined that can be applied to each of the three NCSCS site characteristic categories to improve correlations between NCSCS site scores and PQRA results. In some cases, these factors exclude 1 or 2 of the site characteristic categories (i.e., the corresponding factors are zero) to optimise the site scores. Using these weighting factors, additional equations relating modified NCSCS scores and PQRA results were developed that would not have been reasonable given unmodified NCSCS scores.

Third, predicted cumulative hazard index intervals for the majority of the identified receptors that correspond to the NCSCS class cut off values were determined. Focusing on the Class N and Class 1 cut off values and the modified NCSCS scores, the equations for human receptors predicts midpoint human cumulative hazard indices of 4 and 80 under the known scenario and 20 and 4,000 under the potential scenario. Similarly, ecological receptor cumulative hazard indices under the known scenario range from 0.9 to 9 at the Class N cut off value and from 8 to 90 at the Class 1 cut off value.

Under the potential scenario, the ranges for ecological receptors are 0.2 to 20 at the Class N cut off value and 5 to 400 at the Class 1 cut off value. The average cumulative hazard indices for all ecological receptors are excluded from these ranges because the average considers cumulative hazard indices of zero. In a general sense, cumulative hazard indices for ecological receptors at the Class N cut off value are within an order of magnitude of 1 suggesting the modified NCSCS scores are suitably calibrated at this threshold. The same conclusion doesn't seem to apply to human cumulative hazard indices which are greater than 1 and indicates additional NCSCS calibration is needed to align with the indices. Regarding cumulative hazard indices at the Class 1 cut off value, they are generally 1 to 2 orders of magnitude greater than those at the Class N cut off value.

The validity of these conclusions is dependent on the conditions that the defined receptors must be present at the contaminated site; there are operable exposure routes between contaminants and the receptors; and, there are defined tolerable doses for at least some of the chemicals to which the receptors are exposed.

We recommend that the conclusions presented here be validated with data from additional contaminated sites.

Chapter Seven: Conclusions & Recommendations

The thesis goal was to evaluate the 2008 NCSCS and to propose practical enhancements to the system, as necessary, yet retain its existing simplicity.

7.1 Conclusions

Based on the results presented in Chapters 5 and 6, six conclusions can be made. First, cumulative hazard indices for humans can act as surrogates for some ecological receptors or receptor groups. Under the defined known scenario, human *CI* values are positively correlated with those for plants & soil invertebrates, cows, voles, shrews, kestrels, aquatic life, and the geometric average of ecological receptor *CI* values. Under the potential scenario, human *CI* values are also positively correlated with the same receptors or receptor groups except for plants & invertebrates and kestrels; however, the correlations are not as strong as under the known scenario. Equations that can be used to predict the range of probable ecological receptor *CI* values using human *CI* values have been developed. The equations associated with the known scenario are preferred for use because they exhibit stronger agreement with the data when compared to equations related to the potential scenario.

Second, plants & soil invertebrate *CI* values can also act as surrogates for the following ecological receptor or receptor groups, although the list is limited to the known scenario: cows, voles, shrews, kestrels, and average ecological receptor *CI* values.

Third, based on the first two conclusions, humans are the preferred surrogate for ecological receptors.

Fourth, NCSCS site scores are positively correlated with the cumulative hazard indices for some biological receptors. Under the defined known scenario for the PQRAs,

equations relating cumulative hazard indices for meadow voles, masked shrews, as well as the average cumulative hazard indices for all 7 ecological receptors to NCSCS site scores have been proposed. Similarly for the potential scenario, equations have been developed for the same receptors plus humans, cows, and aquatic life. The equations can be used to estimate contaminated site hazard ranges for specified receptors or receptor groups given an NCSCS site score.

Fifth, receptor and scenario specific weighting factors have been determined that can be applied to each of the three NCSCS site characteristic categories to improve correlations between NCSCS site scores and PQRA results. In some cases, these factors exclude 1 or 2 of the site characteristic categories (i.e., the corresponding factors are zero) to optimise the site scores. Using these weighting factors, additional equations relating modified NCSCS scores and PQRA results were developed that would not have been reasonable given unmodified NCSCS scores.

Finally, predicted cumulative hazard index intervals for the majority of the identified receptors that correspond to the NCSCS class cut off values were determined. Focusing on the Class N and Class 1 cut off values and the modified NCSCS scores, the equations for human receptors predicts midpoint human cumulative hazard indices of 4 and 80 under the known scenario and 20 and 4,000 under the potential scenario. Similarly, ecological receptor cumulative hazard indices under the known scenario range from 0.9 to 9 at the Class N cut off value and from 8 to 90 at the Class 1 cut off value. Under the potential scenario, the ranges for ecological receptors are 0.2 to 20 at the Class N cut off value and 5 to 400 at the Class 1 cut off value. The average cumulative hazard indices for all ecological receptors are excluded from these ranges because the average

considers cumulative hazard indices of zero. In a general sense, cumulative hazard indices for ecological receptors at the Class N cut off value are within an order of magnitude of 1 suggesting the modified NCSCS scores are suitably calibrated at this threshold. The same conclusion doesn't seem to apply to human cumulative hazard indices which are greater than 1 and indicates additional NCSCS calibration is needed to align with the indices. Regarding cumulative hazard indices at the Class 1 cut off value, they are generally 1 to 2 orders of magnitude greater than those at the Class N cut off value.

The validity of these conclusions is dependent on the conditions that the defined receptors must be present at the contaminated site; there are operable exposure routes between contaminants and the receptors; and, there are defined tolerable doses for at least some of the chemicals to which the receptors are exposed.

7.2 Recommendations

Recognizing the limited amount of data used in this research, the conclusions presented should be validated with data from additional contaminated sites sourced from the Federal Contaminated Site Inventory.

Furthermore, NCSCS category weighting factors were proposed in this thesis to improve the correlation between NCSCS scores and PQRA results. Although some improvements resulted, the data scatter is still significant with CI_k prediction intervals ranging over several orders of magnitude. More significant NCSCS modifications are needed to approach a monotonic relationship between NCSCS scores and PQRA results. Fundamental to these modifications is ensuring NCSCS scoring factors are reorganised

and the related scores combined in a manner that is analogous to the source-pathway-receptor concept in human and ecological risk assessment.

The proposed framework is a simplified version of the PQRAs used in this research which incorporates the components summarised in Chapter 3. The metric used to rank and classify sites could be the cumulative hazard index as defined in this research. Since the NCSCS combines contaminant effects to both human and ecological receptors into a single number, receptor specific cumulative hazard indices should be also be combined into a single value that is representative of the hazard at a contaminated site. A possible method of combining ecological receptor cumulative hazard indices is the geometric mean, as performed in this research. Combining human and ecological cumulative hazard indices will also be required. However, key to this effort is achieving agreement among stakeholders affected by these proposed changes to the 2008 NCSCS such as the federal departments, agencies, and crown corporations responsible for managing contaminated sites as well as site tenants and First Nations groups who are exposed or could potentially be exposed to the contaminants at the sites.

Pending the results of the recommended validation exercise and subject to stakeholder approval, perhaps a representative cumulative hazard index for a site, CI_{site}, could be calculated with a CI_{site} of 1 corresponding to the Class N cut off value 37; CI_{site} = 10 corresponding to S_{site} = 50; and CI_{site} = 100 corresponding to S_{site} = 70. Other S_{site} values could be determined based on interpolation between or reasonable extrapolation beyond these cut off CI_{site} values. This is a concept that should be developed in collaborated with the identified stakeholders to ensure the proposed NCSCS revisions are aligned with stakeholders' objectives.

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APPENDIX A: CORRESPONDENCE

APPENDIX B: PQRA INPUT PARAMETER SUMMARY

B.1. Contaminant Properties: K_d, K_{oc}, H', D_a, & D_w

Table B-1 Contaminant Properties: K_d, K_{oc}, H', D_a, & D_w

Contaminant	Distribution coefficient, K_d (mL/g)[1]		Organic carbon partitioning coefficient, K_{oc} (mL/g)		Dimensionless Henry's Constant, H'		Molecular diffusion coefficient in air, D_a (cm^2/s)		Molecular diffusion coefficient in water, D_w (cm^2/s)	
	Value	Reference	Value	Reference	Value	Reference	Value	Reference	Value	Reference
2,3,4,6-Tetrachlorophenol	1.00E+01	calculated	2.00E+03	ORNL 2009	3.61E-04	ORNL 2009	-	-	-	-
2-Chlorophenol	2.22E+00	calculated	4.43E+02	ORNL 2009	4.58E-04	ORNL 2009	6.6E-06	ORNL 2009	9.48E-06	ORNL 2009
2,4-Dimethylphenol	3.59E+00	calculated	7.18E+02	ORNL 2009	3.89E-05	ORNL 2009	6.2E-02	ORNL 2009	8.31E-06	ORNL 2009
Acenaphthene	1.41E+01	calculated	2.82E+03	CCME 2008b	6.56E-03	CCME 2008b	4.2E-02	CCME 2008b	8.33E-06	ORNL 2009
Acenaphthylene	2.81E+01	calculated	5.62E+03	CCME 2008b	4.78E-04	CCME 2008b	4.50E-02	CCME 2008b	6.98E-06	ORNL 2009
Aliphatic $C_{>10}$-C_{12}	1.26E+03	calculated	2.51E+05	CCME 2008a	1.20E+02	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aliphatic $C_{>12}$-C_{16}	2.51E+04	calculated	5.01E+06	CCME 2008a	5.20E+02	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aliphatic $C_{>16}$-C_{21}	3.16E+06	calculated	6.31E+08	CCME 2008a	4.90E+03	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aliphatic $C_{>21}$-C_{34}	5.00E+10	Assumed as Na	1.00E+13	CCME 2008a	5.60E+05	CCME 2008a	5.00E-02	CCME 2008a	-	-
Aliphatic $C_{>34}$	8.00E+05	calculated	1.60E+08	CCME 2008a	1.20E+08	CCME 2008a	5.00E-02	CCME 2008a	-	-
Aliphatic $C_{>8}$-C_{10}	1.58E+02	calculated	3.16E+04	CCME 2008a	8.00E+01	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aliphatic C_6-C_8	1.99E+01	calculated	3.98E+03	CCME 2008a	5.00E+01	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aluminum	9.90E+00	ORNL 2009	-	-	-	-	-	-	-	-
Ammonia	9.90E+00	ORNL 2009	-	-	6.88E-04	USEPA 2009	-	-	-	-
Anthracene	9.98E+01	CCME 2008b	2.00E+04	CCME 2008b	1.50E-03	CCME 2008b	3.24E-02	USEPA 1996	7.85E-06	ORNL 2009
Antimony	4.50E+01	USEPA 1996	-	-	-	-	-	-	-	-
Aromatic $C_{>10}$-C_{12}	1.26E+01	calculated	2.51E+03	CCME 2008a	1.40E-01	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aromatic $C_{>12}$-C_{16}	2.51E+01	calculated	5.01E+03	CCME 2008a	5.30E-02	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aromatic $C_{>16}$-C_{21}	7.92E+01	calculated	1.58E+04	CCME 2008a	1.30E-02	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aromatic $C_{>21}$-C_{34}	6.29E+02	calculated	1.26E+05	CCME 2008a	6.70E-04	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Aromatic $C_{>34}$	9.00E+03	calculated	1.80E+06	CCME 2008a	1.80E-05	CCME 2008a	5.00E-02	CCME 2008a	-	-
Aromatic $C_{>8}$-C_{10}	7.93E+00	calculated	1.59E+03	CCME 2008a	4.80E-01	CCME 2008a	5.00E-02	CCME 2008a	1.00E-05	Gustafson et al. 1997
Arsenic	2.90E+01	USEPA 1996	-	-	-	-	-	-	-	-
Barium	4.10E+01	USEPA 1996	-	-	-	-	-	-	-	-
Benzo[a]anthracene	9.98E+02	calculated	2.00E+05	CCME 2008b	1.42E-04	CCME 2008b	5.01E-02	USEPA 1996	-	-
Benzene	4.05E-01	calculated	8.10E+01	CCME 2009	2.25E-01	CCME 2009	8.80E-02	CCME 2009	9.80E-06	Gustafson et al. 1997
Benzo[a]pyrene	1.09E+04	calculated	2.19E+06	CCME 2008b	4.78E-05	CCME 2008b	4.30E-02	USEPA 1996	-	-
Benzo[b,j]fluoranthene	4.67E+02	calculated	9.33E+04	CCME 2008b	4.68E-04	CCME 2008b	2.26E-02	USEPA 1996	-	-

Table B-1 Contaminant Properties: K_d, K_{oc}, H', D_a, & D_w

Contaminant	Distribution coefficient, K_d (mL/g)[1]		Organic carbon partitioning coefficient, K_{oc} (mL/g)		Dimensionless Henry's Constant, H'		Molecular diffusion coefficient in air, D_a (cm^2/s)		Molecular diffusion coefficient in water, D_w (cm^2/s)	
	Value	Reference	Value	Reference	Value	Reference	Value	Reference	Value	Reference
Benzo[g,h,i]perylene	2.04E+03	calculated	4.07E+05	CCME 2008b	5.97E-06	CCME 2008b	-	-	-	-
Benzo[k]fluoranthene	9.98E+01	calculated	2.00E+04	CCME 2008b	3.51E-05	CCME 2008b	2.26E-02	USEPA 1996	-	-
Beryllium	7.90E+02	USEPA 1996	-	-	-	-	-	-	-	-
Cadmium	7.50E+01	USEPA 1996	-	-	-	-	-	-	-	-
Chloride	1.15E-01	Assumed as Na	-	-	-	-	-	-	-	-
Chromium (hexavalent)	1.90E+01	USEPA 2009	-	-	-	-	-	-	-	-
Chromium (total)	1.90E+01	USEPA 2009	-	-	-	-	-	-	-	-
Chrysene	6.29E+02	calculated	1.26E+05	CCME 2008b	4.00E-03	CCME 2008b	2.48E-02	USEPA 1996	-	-
Cobalt	4.50E+01	USEPA 2009	-	-	-	-	-	-	-	-
Conductivity (dS/m)	-	-	-	-	-	-	-	-	-	-
Copper	4.30E+02	USEPA 2009	-	-	-	-	-	-	-	-
Cresol-o	2.22E+00	calculated	4.43E+02	ORNL 2009	4.91E-05	ORNL 2009	7.29E-02	ORNL 2009	9.32E-06	ORNL 2009
Cresol-m	2.17E+00	calculated	4.34E+02	ORNL 2009	3.50E-05	ORNL 2009	7.29E-02	ORNL 2009	9.32E-06	ORNL 2009
Cresol-p	2.17E+00	calculated	4.34E+02	ORNL 2009	4.09E-05	ORNL 2009	7.29E-02	ORNL 2009	9.32E-06	ORNL 2009
Cyanide	9.90E+00	USEPA 1996	-	-	1.03E+00	USEPA 2009	-	-	-	-
DDT	3.97E+03	calculated	7.94E+05	ORNL 2009	3.40E-04	ORNL 2009	1.37E-02	ORNL 2009	-	-
Dibenzo[a,h]anthracene	6.90E+03	calculated	1.38E+06	CCME 2008b	6.22E-07	CCME 2008b	2.02E-02	USEPA 1996	-	-
Dichloromethane	1.19E-01	calculated	2.37E+01	ORNL 2009	1.33E-01	ORNL 2009	1.01E-01	ORNL 2009	1.17E-05	USEPA 1996
Dioxin and furans (1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin)	1.70E+07	USEPA 2009	-	-	7.31E-03	USEPA 2009	-	-	-	-
Ethylbenzene	2.69E+00	calculated	5.37E+02	CCME 2009	3.58E-01	CCME 2009	7.50E-02	CCME 2009	7.80E-06	Gustafson et al. 1997
F1 (C_6-C_{10})	-	-	-	-	-	-	-	-	-	-
F2 ($C_{>10}$-C_{16})	-	-	-	-	-	-	-	-	-	-
F3 ($C_{>16}$-C_{34})	-	-	-	-	-	-	-	-	-	-
F4 ($C_{>34}$)	-	-	-	-	-	-	-	-	-	-
Fluoranthene	2.08E+02	calculated	4.17E+04	CCME 2008b	6.09E-04	CCME 2008b	3.03E-02	USEPA 1996	-	-
Fluorene	2.45E+01	calculated	4.90E+03	CCME 2008b	3.37E-03	CCME 2008b	3.63E-02	USEPA 1996	7.89E-06	ORNL 2009

Table B-1 Contaminant Properties: K_d, K_{oc}, H', D_a, & D_w

Contaminant	Distribution coefficient,		Organic carbon		Dimensionless Henry's		Molecular diffusion		Molecular diffusion coefficient	
	Value	Reference	Value	Reference	Value	Reference	Value	Reference	Value	Reference
Indeno[1,2,3-c,d]pyrene	7.92E+03	calculated	1.58E+06	CCME 2008b	6.77E-05	CCME 2008b	1.90E-02	USEPA 1996	-	-
Iron	2.50E+01	USEPA 2009	-	-	-	-	-	-	-	-
Lead	9.00E+02	USEPA 2009	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-	-
Mercury	5.20E+01	USEPA 1996	-	-	4.67E-01	USEPA 1996	7.15E-02	ORNL 2009	3.01E-05	ORNL 2009
Molybdenum	-	-	-	-	-	-	-	-	-	-
MTBE	6.00E-02	calculated	1.20E+01	AENV 2009a	2.30E-02	AENV 2009a	1.02E-01	ORNL 2009	8.59E-06	ORNL 2009
Naphthalene	3.54E+00	calculated	7.08E+02	CCME 2008b	2.04E-02	CCME 2008b	5.90E-02	USEPA 1996	8.38E-06	ORNL 2009
Nickel	6.50E+01	USEPA 1996	-	-	-	-	-	-	-	-
PCBs (Aroclor 1254)	5.90E+05	USEPA 2009	-	-	1.12E-01	USEPA 2009	-	-	-	-
Pentachlorophenol	1.25E+01	calculated	2.50E+03	ORNL 2009	1.00E-06	ORNL 2009	5.60E-02	ORNL 2009	-	-
Phenanthrene	3.30E+01	calculated	6.61E+03	CCME 2008b	9.86E-04	CCME 2008b	2.72E-02	USEPA 1996	6.69E-06	ORNL 2009
Phenol	6.00E-02	calculated	1.20E+01	CCME 2009	1.60E-05	CCME 2009	8.20E-02	ORNL 2009	1.03E-05	ORNL 2009
Pyrene	3.46E+02	calculated	6.92E+04	CCME 2008b	4.66E-04	CCME 2008b	2.72E-02	USEPA 1996	7.25E-06	ORNL 2009
Selenium	5.00E+00	USEPA 1996	-	-	-	-	-	-	-	-
Silver	8.30E+00	USEPA 1996	-	-	-	-	-	-	-	-
Sodium	-	-	-	-	-	-	-	-	-	-
Sodium adsorption ratio	-	-	-	-	-	-	-	-	-	-
Styrene	2.31E+00	calculated	4.61E+02	AENV 2009a	1.23E-01	AENV 2009a	7.10E-02	Gustafson et al. 1997	8.00E-06	Gustafson et al. 1997
Sulphate	-	-	-	-	-	-	-	-	-	-
Tetrachloroethene	1.33E+00	calculated	2.65E+02	USEPA 1996	7.54E-01	USEPA 1996	7.20E-02	USEPA 1996	8.20E-06	USEPA 1996
Tetrachloromethane	7.60E-01	calculated	1.52E+02	USEPA 1996	1.25E+00	USEPA 1996	7.80E-02	USEPA 1996	8.80E-06	USEPA 1996
Thallium	7.10E+01	USEPA 1996	-	-	-	-	-	-	-	-
Tin	-	-	-	-	-	-	-	-	-	-
Toluene	1.17E+00	calculated	2.34E+02	CCME 2009	2.74E-01	CCME 2009	8.70E-02	CCME 2009	8.60E-06	Gustafson et al. 1997
Trichloroethene	4.70E-01	calculated	9.40E+01	USEPA 1996	4.22E-01	USEPA 1996	7.90E-02	USEPA 1996	9.10E-06	USEPA 1996
Vinyl Chloride	9.30E-02	calculated	1.86E+01	USEPA 1996	1.11E+00	USEPA 1996	1.06E-01	USEPA 1996	1.23E-06	USEPA 1996
Xylenes	2.93E+00	calculated	5.86E+02	CCME 2009	2.52E-01	CCME 2009	7.80E-02	CCME 2009	8.80E-06	Gustafson et al. 1997
Zinc	6.20E+01	USEPA 1996	-	-	-	-	-	-	-	-

Notes:

[1] For organic chemials, K_d calculated from $K_d \times f_{oc}$ where f_{oc} is 0.005 (CCME 2006). For inorganics, referenced K_d is at pH near 7.

B.2. Contaminant Properties: S, p_v, M_w, $t_{1/2us}$, & $t_{1/2s}$

Table B-2 Contaminant Properties: S, p_v, M_w, $t_{1/2us}$, & $t_{1/2s}$

Contaminant	Water solubility, S (mg/L)		Vapour pressure, p_v (atm)		Molecular weight, M_w (g/mol)		Half Life, $t_{1/2}$ (years)		
	Value	Reference	Value	Reference	Value	Reference	$t_{1/2s}$ (years)	$t_{1/2us}$ (years)	Reference
2,3,4,6-Tetrachlorophenol	2.30E+01	ORNL 2009	8.8E-07	ORNL 2009	232	ORNL 2009	9.86E-01	9.86E-01	Mackay et al. 2006
2-Chlorophenol	2.85E+04	ORNL 2009	0.0E+00	ORNL 2009	129	ORNL 2009	9.99E+02	9.99E+02	Assumed
2,4-Dimethylphenol	7.87E+03	ORNL 2009	0.0E+00	ORNL 2009	122	ORNL 2009	7.67E-02	7.67E-02	Mackay et al. 2006
Acenaphthene	3.90E+00	CCME 2008b	2.8E-06	ORNL 2009	154	ORNL 2009	1.12E+00	1.12E+00	Mackay et al. 2006
Acenaphthylene	1.61E+01	CCME 2008b	8.8E-06	ORNL 2009	152	ORNL 2009	6.58E-01	6.58E-01	Mackay et al. 2006
Aliphatic C>10-C12	3.40E-02	CCME 2008a	6.3E-04	Gustafson et al. 1997	160	Gustafson et al. 1997	4.79E+00	4.79E+00	CCME 2008a
Aliphatic C>12-C16	7.60E-04	CCME 2008a	4.8E-05	Gustafson et al. 1997	200	Gustafson et al. 1997	4.79E+00	4.79E+00	CCME 2008a
Aliphatic C>16-C21	2.50E-06	CCME 2008a	1.1E-06	Gustafson et al. 1997	270	Gustafson et al. 1997	9.99E+02	9.99E+02	Assumed
Aliphatic C>21-C34	-	-	-	-	-	-	9.99E+02	9.99E+02	Assumed
Aliphatic C>34	-	-	-	-	-	-	9.99E+02	9.99E+02	Assumed
Aliphatic C>8-C10	4.30E-01	CCME 2008a	6.3E-03	Gustafson et al. 1997	130	Gustafson et al. 1997	1.95E+00	1.95E+00	CCME 2008a
Aliphatic C6-C8	5.40E+00	CCME 2008a	6.3E-02	Gustafson et al. 1997	100	Gustafson et al. 1997	1.95E+00	1.95E+00	CCME 2008a
Aluminum	9.50E+04	USEPA 2009	-	-	27	USEPA 2009	1.00E+06	1.00E+06	Not biodegradable
Ammonia	4.80E+05	USEPA 2009	9.9E+00	USEPA 2009	17	USEPA 2009	9.99E+02	9.99E+02	Assumed
Anthracene	5.70E-02	CCME 2008b	8.6E-09	ORNL 2009	178	ORNL 2009	5.04E+00	5.04E+00	Mackay et al. 2006
Antimony	1.70E+05	USEPA 2009	-	-	125	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Aromatic C>10-C12	2.50E+01	CCME 2008a	6.3E-04	Gustafson et al. 1997	130	Gustafson et al. 1997	4.79E+00	4.79E+00	CCME 2008a
Aromatic C>12-C16	5.80E+00	CCME 2008a	4.8E-05	Gustafson et al. 1997	150	Gustafson et al. 1997	4.79E+00	4.79E+00	CCME 2008a
Aromatic C>16-C21	6.50E-01	CCME 2008a	1.1E-06	Gustafson et al. 1997	190	Gustafson et al. 1997	9.99E+02	9.99E+02	Assumed
Aromatic C>21-C34	6.60E-03	CCME 2008a	4.4E-10	Gustafson et al. 1997	240	Gustafson et al. 1997	9.99E+02	9.99E+02	Assumed
Aromatic C>34	-	-	-	-	-	-	9.99E+02	9.99E+02	Assumed
Aromatic C>8-C10	6.50E+01	CCME 2008a	6.3E-03	Gustafson et al. 1997	120	Gustafson et al. 1997	1.95E+00	1.95E+00	CCME 2008a
Arsenic	1.20E+05	USEPA 2009	-	-	78	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Barium	2.80E+03	USEPA 2009	-	-	137	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Benzo[a]anthracene	9.40E-03	CCME 2008b	2.8E-10	ORNL 2009	228	ORNL 2009	7.45E+00	7.45E+00	Mackay et al. 2006
Benzene	1.78E+03	Gustafson et al. 1997	1.3E-01	Gustafson et al. 1997	78	Gustafson et al. 1997	1.00E+00	5.00E-01	BCMELP 1996
Benzo[a]pyrene	1.60E-03	CCME 2008b	7.2E-12	ORNL 2009	252	ORNL 2009	2.90E+00	1.45E+00	BCMELP 1996
Benzo[b,j]fluoranthene	3.75E-03	CCME 2008b	6.6E-10	ORNL 2009	252	ORNL 2009	6.68E+00	6.68E+00	Mackay et al. 2006
Benzo[g,h,i]perylene	2.60E-05	CCME 2008b	1.3E-13	ORNL 2009	276	ORNL 2009	7.12E+00	7.12E+00	Mackay et al. 2006
Benzo[k]fluoranthene	8.00E-04	CCME 2008b	1.3E-12	ORNL 2009	252	ORNL 2009	2.35E+01	2.35E+01	Mackay et al. 2006
Beryllium	8.40E+04	USEPA 2009	-	-	9	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable

Table B-2 Contaminant Properties: S, p_v, M_w, $t_{1/2us}$, & $t_{1/2s}$

Contaminant	Water solubility, S (mg/L)		Vapour pressure, p_v (atm)		Molecular weight, M_w (g/mol)		Half Life, $t_{1/2}$ (years)		
	Value	Reference	Value	Reference	Value	Reference	$t_{1/2s}$ (years)	$t_{1/2us}$ (years)	Reference
Cadmium	1.70E+03	USEPA 2009	-	-	112	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Chloride	2.50E+03	Assumed as Na	-	-	36	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Chromium (hexavalent)	6.00E+05	USEPA 2009	-	-	-	-	1.00E+06	1.00E+06	Not biodegradable
Chromium (total)	6.00E+05	USEPA 2009	-	-	-	-	1.00E+06	1.00E+06	Not biodegradable
Chrysene	4.15E-03	CCME 2008b	8.2E-12	ORNL 2009	228	ORNL 2009	1.10E+01	1.10E+01	Mackay et al. 2006
Cobalt	1.70E+03	USEPA 2009	0.0E+00	ORNL 2009	59	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Conductivity (dS/m)	-	-	-	-	-	-	-	-	-
Copper	5.70E+02	USEPA 2009	-	-	64	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Cresol-o	2.59E+04	ORNL 2009	-	-	108	ORNL 2009	7.67E-02	7.67E-02	Mackay et al. 2006
Cresol-m	2.27E+04	ORNL 2009	-	-	108	ORNL 2009	1.34E-01	1.34E-01	Mackay et al. 2006
Cresol-p	2.15E+04	ORNL 2009	-	-	108	ORNL 2009	7.67E-02	7.67E-02	Mackay et al. 2006
Cyanide	1.00E+06	Assumed	4.1E-01	USEPA 2009	27	ORNL 2009	9.99E+02	9.99E+02	Assumed
DDT	5.50E-03	ORNL 2009	2.1E-10	ORNL 2009	354	ORNL 2009	3.13E+01	3.13E+01	Mackay et al. 2006
Dibenzo[a,h]anthracene	2.49E-03	CCME 2008b	1.3E-12	ORNL 2009	278	ORNL 2009	5.15E+00	5.15E+00	Mackay et al. 2006
Dichloromethane	1.30E+03	ORNL 2009	5.7E-01	ORNL 2009	85	ORNL 2009	3.07E-01	3.07E-01	Mackay et al. 2006
Dioxin and furans (1,2,3,4,	2.40E-06	USEPA 2009	-	-	-	-	6.47E+00	6.47E+00	Mackay et al. 2006
Ethylbenzene	1.52E+02	Gustafson et al. 1997	1.3E-02	Gustafson et al. 1997	106	Gustafson et al. 1997	3.12E-01	3.12E-01	BCMELP 1996
F1 (C6-C10)	-	-	-	-	-	-	1.95E+00	-	CCME 2008a
F2 (C>10-C16)	-	-	-	-	-	-	4.79E+00	-	CCME 2008a
F3 (C>16-C34)	-	-	-	-	-	-	-	-	-
F4 (C>34)	-	-	-	-	-	-	-	-	-
Fluoranthene	2.60E-01	CCME 2008b	1.2E-08	ORNL 2009	202	ORNL 2009	4.82E+00	4.82E+00	Mackay et al. 2006
Fluorene	1.90E+00	CCME 2008b	7.9E-07	ORNL 2009	166	ORNL 2009	6.58E-01	6.58E-01	Mackay et al. 2006
Indeno[1,2,3-c,d]pyrene	2.20E-05	CCME 2008b	1.6E-13	ORNL 2009	276	ORNL 2009	9.99E+02	9.99E+02	Assumed
Iron	1.50E+03	USEPA 2009	-	-	56	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Lead	8.70E+02	USEPA 2009	-	-	207	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Manganese	-	-	-	-	-	-	1.00E+06	1.00E+06	Not biodegradable
Mercury	4.50E+02	USEPA 2009	2.7E-06	USEPA 2009	201	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Molybdenum	-	-	-	-	96	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
MTBE	5.10E+04	AENV 2009a	3.3E-01	ORNL 2009	88	ORNL 2009	9.99E+02	9.99E+02	Assumed
Naphthalene	3.17E+01	CCME 2008b	1.1E-04	ORNL 2009	128	ORNL 2009	3.50E-01	1.80E-01	BCMELP 1996

Table B-2 Contaminant Properties: S, p_v, M_w, $t_{1/2us}$, & $t_{1/2s}$

Contaminant	Water solubility, S (mg/L)		Vapour pressure, p_v (atm)		Molecular weight, M_w (g/mol)		Half Life, $t_{1/2}$ (years)		
	Value	Reference	Value	Reference	Value	Reference	$t_{1/2s}$ (years)	$t_{1/2us}$ (years)	Reference
Nickel	1.50E+03	USEPA 2009	-	-	59	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
PCBs (Aroclor 1254)	7.00E-01	USEPA 2009	-	-	292	ORNL 2009	9.99E+02	9.99E+02	Assumed
Pentachlorophenol	1.40E+01	ORNL 2009	1.4E-07	ORNL 2009	266	ORNL 2009	2.10E+00	1.05E+00	BCMELP 1996
Phenanthrene	1.15E+00	CCME 2008b	1.6E-07	ORNL 2009	178	ORNL 2009	2.19E+00	2.19E+00	Mackay et al. 2006
Phenol	8.70E+04	CCME 2009	4.6E-04	ORNL 2009	94	ORNL 2009	1.92E-02	1.92E-02	Mackay et al. 2006
Pyrene	1.35E+00	CCME 2008b	5.9E-09	ORNL 2009	202	ORNL 2009	1.04E+01	5.20E+00	BCMELP 1996
Selenium	2.60E+06	USEPA 2009	-	-	81	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Silver	2.50E+02	USEPA 2009	-	-	108	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Sodium	2.50E+03	ORNL 2009	-	-	23	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Sodium adsorption ratio	-	-	-	-	-	-	-	-	-
Styrene	3.00E+02	Gustafson et al. 1997	7.9E-03	Gustafson et al. 1997	104	Gustafson et al. 1997	3.07E-01	3.07E-01	Mackay et al. 2006
Sulphate	-	-	-	-	98	ORNL 2009	-	-	-
Tetrachloroethene	2.00E+02	USEPA 1996	2.0E-02	ORNL 2009	166	ORNL 2009	2.25E+00	1.13E+00	BCMELP 1996
Tetrachloromethane	7.93E+02	USEPA 1996	1.5E-01	ORNL 2009	154	ORNL 2009	9.86E-01	9.86E-01	Mackay et al. 2006
Thallium	8.60E+03	USEPA 2009	-	-	-	-	1.00E+06	1.00E+06	Not biodegradable
Tin	-	-	-	-	121	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable
Toluene	5.15E+02	Gustafson et al. 1997	3.8E-02	Gustafson et al. 1997	92	Gustafson et al. 1997	2.88E-01	1.53E-01	BCMELP 1996
Trichloroethene	1.10E+03	USEPA 1996	8.3E-01	ORNL 2009	97	ORNL 2009	2.25E+00	1.13E+00	BCMELP 1996
Vinyl Chloride	2.76E+03	USEPA 1996	3.9E+00	ORNL 2009	63	ORNL 2009	1.97E+00	1.97E+00	Mackay et al. 2006
Xylenes	1.98E+02	Gustafson et al. 1997	1.2E-02	Gustafson et al. 1997	106	Gustafson et al. 1997	5.01E-01	5.01E-01	BCMELP 1996
Zinc	1.40E+03	ORNL 2009	-	-	65	ORNL 2009	1.00E+06	1.00E+06	Not biodegradable

B.3. Human Absorption and Biotransfer Factors

Table B-3 Human Absorption and Biotransfer Factors

Contaminant	Human absorption factors, *AF*						Biotransfer factors to beef & milk (d/kg)			
	Gut	Reference	Skin	Reference	Lung	Reference	Beef	Reference	Milk	Reference
2,3,4,6-Tetrachlorophenol	1.00	AENV 2009a	1.00	AENV 2009a	1.00	AENV 2009a	7.3E-05	USEPA 2005	1.5E-05	USEPA 2005
2-Chlorophenol	1.00	Assumed	1.00	Assumed	1.00	Assumed	4.0E-06	ORNL 2009	1.3E-06	ORNL 2009
2,4-Dimethylphenol	1.00	Assumed	0.26	HC 2004a	1.00	Assumed	5.0E-06	ORNL 2009	1.6E-06	ORNL 2009
Acenaphthene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	2.4E-02	USEPA 2005	5.1E-03	USEPA 2005
Acenaphthylene	1.00	AENV 2009a	0.18	CCME 2008a	1.00	AENV 2009a	-	-	-	-
Aliphatic $C_{>10}$-C_{12}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	4.0E-02	USEPA 2005	8.5E-03	USEPA 2005
Aliphatic $C_{>12}$-C_{16}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	2.4E-02	USEPA 2005	5.1E-03	USEPA 2005
Aliphatic $C_{>16}$-C_{21}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	6.9E-03	USEPA 2005	1.4E-03	USEPA 2005
Aliphatic $C_{>21}$-C_{34}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-
Aliphatic $C_{>34}$	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-
Aliphatic $C_{>8}$-C_{10}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	3.6E-02	USEPA 2005	7.7E-03	USEPA 2005
Aliphatic C_6-C_8	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	2.3E-02	USEPA 2005	4.8E-03	USEPA 2005
Aluminum	1.00	Assumed	-	-	1.00	Assumed	1.5E-03	Baes et al. 1984	2.0E-04	Baes et al. 1984
Ammonia	1.00	Assumed	-	-	1.00	Assumed	-	-	-	-
Anthracene	1.00	AENV 2009a	0.29	CCME 2008a	1.00	AENV 2009a	3.4E-02	USEPA 2005	7.1E-03	USEPA 2005
Antimony	1.00	Assumed	0.10	HC 2004a	1.00	Assumed	1.0E-03	Baes et al. 1984	1.0E-04	Baes et al. 1984
Aromatic $C_{>10}$-C_{12}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	2.0E-02	USEPA 2005	4.1E-03	USEPA 2005
Aromatic $C_{>12}$-C_{16}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	2.4E-02	USEPA 2005	5.2E-03	USEPA 2005
Aromatic $C_{>16}$-C_{21}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	3.2E-02	USEPA 2005	6.8E-03	USEPA 2005
Aromatic $C_{>21}$-C_{34}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	4.1E-02	USEPA 2005	8.6E-03	USEPA 2005
Aromatic $C_{>34}$	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-
Aromatic $C_{>8}$-C_{10}	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	1.6E-02	USEPA 2005	3.5E-03	USEPA 2005
Arsenic	1.00	AENV 2009a	0.03	HC 2004a	1.00	AENV 2009a	2.0E-03	Baes et al. 1984	6.0E-05	Baes et al. 1984
Barium	1.00	AENV 2009a	0.10	HC 2004a	1.00	AENV 2009a	1.5E-04	Baes et al. 1984	3.5E-04	Baes et al. 1984

Table B-3 Human Absorption and Biotransfer Factors

Contaminant	Human absorption factors, *AF*						Biotransfer factors to beef & milk (d/kg)			
	Gut	Reference	Skin	Reference	Lung	Reference	Beef	Reference	Milk	Reference
Benzo[a]anthracene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	4.0E-02	USEPA 2005	8.4E-03	USEPA 2005
Benzene	1.00	AENV 2009a	0.08	HC 2004a	1.00	AENV 2009a	3.4E-03	USEPA 2005	7.1E-04	USEPA 2005
Benzo[a]pyrene	1.00	AENV 2009a	0.34	CCME 2008a	1.00	AENV 2009a	3.4E-02	ORNL 2009	1.1E-02	ORNL 2009
Benzo[b,j]fluoranthene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	1.5E-02	ORNL 2009	4.8E-03	ORNL 2009
Benzo[g,h,i]perylene	1.00	AENV 2009a	0.18	CCME 2008a	1.00	AENV 2009a	-	-	-	-
Benzo[k]fluoranthene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	3.6E-02	USEPA 2005	7.7E-03	USEPA 2005
Beryllium	1.00	Assumed	0.03	HC 2004a	1.00	Assumed	1.0E-03	Baes et al. 1984	9.0E-07	Baes et al. 1984
Cadmium	1.00	Assumed	0.14	HC 2004a	1.00	Assumed	5.5E-04	Baes et al. 1984	1.0E-03	Baes et al. 1984
Chloride	1.00	Assumed	-	-	1.00	Assumed	-	-	-	-
Chromium (hexavalent)	1.00	Assumed	0.09	HC 2004a	1.00	Assumed	5.5E-03	Baes et al. 1984	1.5E-03	Baes et al. 1984
Chromium (total)	1.00	Assumed	0.13	HC 2004a	1.00	Assumed	5.5E-03	Baes et al. 1984	1.5E-03	Baes et al. 1984
Chrysene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-
Cobalt	1.00	Assumed	0.10	HC 2004a	1.00	Assumed	2.0E-02	Baes et al. 1984	2.0E-03	Baes et al. 1984
Copper	1.00	Assumed	0.10	HC 2004a	1.00	Assumed	1.0E-02	Baes et al. 1984	1.5E-03	Baes et al. 1984
Cresol-o	1.00	ORNL 2009	0.10	ORNL 2009	1.00	ORNL 2009	2.0E-06	ORNL 2009	6.3E-07	ORNL 2009
Cresol-m	1.00	ORNL 2009	0.10	ORNL 2009	1.00	ORNL 2009	2.5E-06	ORNL 2009	7.9E-07	ORNL 2009
Cresol-p	1.00	ORNL 2009	0.10	ORNL 2009	1.00	ORNL 2009	2.0E-06	ORNL 2009	6.3E-07	ORNL 2009
Cyanide	1.00	Assumed	0.30	HC 2004a	1.00	Assumed	9.1E-06	USEPA 2005	1.9E-06	USEPA 2005
DDT	1.00	AENV 2009a	0.20	HC 2004a	1.00	AENV 2009a	3.2E-02	USEPA 2005	6.8E-03	USEPA 2005
Dibenzo[a,h]anthracene	1.00	AENV 2009a	0.09	CCME 2008a	1.00	AENV 2009a	3.1E-02	USEPA 2005	6.5E-03	USEPA 2005
Dichloromethane	1.00	AENV 2009a	1.00	AENV 2009a	1.00	AENV 2009a	8.8E-04	USEPA 2005	1.8E-04	USEPA 2005
Dioxin and furans	1.00	AENV 2009a	1.00	AENV 2009a	1.00	AENV 2009a	1.5E-04	USEPA 2005	3.3E-05	USEPA 2005
Ethylbenzene	1.00	AENV 2009a	0.20	HC 2004a	1.00	AENV 2009a	1.2E-02	USEPA 2005	2.6E-03	USEPA 2005
F1 (C_6-C_{10})	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-
F2 ($C_{>10}$-C_{16})	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-
F3 ($C_{>16}$-C_{34})	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-

Table B-3 Human Absorption and Biotransfer Factors

Contaminant	Human absorption factors, *AF*						Biotransfer factors to beef & milk (d/kg)			
	Gut	Reference	Skin	Reference	Lung	Reference	Beef	Reference	Milk	Reference
F4 ($C_{>34}$)	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	-	-	-	-
Fluoranthene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	3.9E-02	USEPA 2005	8.3E-03	USEPA 2005
Fluorene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	2.9E-02	USEPA 2005	6.2E-03	USEPA 2005
Indeno[1,2,3-c,d]pyrene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	2.9E-02	USEPA 2005	6.2E-03	USEPA 2005
Iron	1.00	Assumed	-	-	1.00	Assumed	2.0E-02	Baes et al. 1984	2.5E-04	Baes et al. 1984
Lead	1.00	Assumed	0.006	HC 2004a	1.00	Assumed	3.0E-04	Baes et al. 1984	2.5E-04	Baes et al. 1984
Manganese	1.00	Assumed	-	-	1.00	Assumed	4.0E-04	Baes et al. 1984	3.5E-04	Baes et al. 1984
Mercury	1.00	Assumed	0.05	HC 2004a	1.00	Assumed	2.5E-01	Baes et al. 1984	4.5E-04	Baes et al. 1984
Molybdenum	1.00	AENV 2009a	0.10	HC 2004a	1.00	AENV 2009a	6.0E-03	Baes et al. 1984	1.5E-03	Baes et al. 1984
MTBE	1.00	AENV 2009a	0.10	HC 2004a	1.00	AENV 2009a	-	-	-	-
Naphthalene	1.00	AENV 2009a	0.10	HC 2004a	1.00	AENV 2009a	1.5E-02	USEPA 2005	3.1E-03	USEPA 2005
Nickel	1.00	Assumed	0.35	HC 2004a	1.00	Assumed	6.0E-03	Baes et al. 1984	1.0E-03	Baes et al. 1984
PCBs (Aroclor 1254)	1.00	AENV 2009a	1.00	AENV 2009a	1.00	AENV 2009a	3.1E-02	USEPA 2005	6.5E-03	USEPA 2005
Pentachlorophenol	1.00	AENV 2009a	0.11	HC 2004a	1.00	AENV 2009a	6.6E-05	USEPA 2005	1.4E-05	USEPA 2005
Phenanthrene	1.00	AENV 2009a	0.18	CCME 2008a	1.00	AENV 2009a	3.4E-02	USEPA 2005	7.1E-03	USEPA 2005
Phenol	1.00	AENV 2009a	0.26	HC 2004a	1.00	AENV 2009a	1.3E-03	USEPA 2005	2.7E-04	USEPA 2005
Pyrene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	3.8E-02	USEPA 2005	8.1E-03	USEPA 2005
Selenium	1.00	AENV 2009a	0.002	HC 2004a	1.00	AENV 2009a	1.5E-02	Baes et al. 1984	4.0E-03	Baes et al. 1984
Silver	1.00	AENV 2009a	0.25	HC 2004a	1.00	AENV 2009a	3.0E-03	Baes et al. 1984	2.0E-02	Baes et al. 1984
Sodium	1.00	Assumed	-	-	1.00	Assumed	5.5E-02	Baes et al. 1984	3.5E-02	Baes et al. 1984
Styrene	1.00	AENV 2009a	0.20	CCME 2008a	1.00	AENV 2009a	1.1E-02	USEPA 2005	2.3E-03	USEPA 2005
Sulphate	1.00	Assumed	-	-	1.00	Assumed	-	-	-	-
Tetrachloroethene	1.00	AENV 2009a	0.10	HC 2004a	1.00	AENV 2009a	1.6E-02	USEPA 2005	3.4E-03	USEPA 2005
Tetrachloromethane	1.00	AENV 2009a	0.10	HC 2004a	1.00	AENV 2009a	8.7E-03	USEPA 2005	1.8E-03	USEPA 2005
Thallium	1.00	Assumed	0.01	HC 2004a	1.00	Assumed	4.0E-02	Baes et al. 1984	2.0E-03	Baes et al. 1984
Tin	1.00	Assumed	-	-	1.00	Assumed	8.0E-02	Baes et al. 1984	1.0E-03	Baes et al. 1984
Toluene	1.00	AENV 2009a	0.12	CCME 2008a	1.00	AENV 2009a	7.7E-03	USEPA 2005	1.6E-03	USEPA 2005

Table B-3 Human Absorption and Biotransfer Factors

Contaminant	Human absorption factors, *AF*						Biotransfer factors to beef & milk (d/kg)			
	Gut	Reference	Skin	Reference	Lung	Reference	Beef	Reference	Milk	Reference
Trichloroethene	1.00	AENV 2009a	0.10	HC 2004a	1.00	AENV 2009a	5.2E-03	USEPA 2005	1.1E-03	USEPA 2005
Vinyl Chloride	1.00	AENV 2009a	0.16	HC 2004a	1.00	AENV 2009a	1.1E-03	USEPA 2005	2.2E-04	USEPA 2005
Xylenes	1.00	AENV 2009a	0.12	CCME 2008a	1.00	AENV 2009a	1.2E-02	USEPA 2005	2.6E-03	USEPA 2005
Zinc	1.00	Assumed	0.02	HC 2004a	1.00	Assumed	1.0E-01	Baes et al. 1984	1.0E-01	Baes et al. 1984

B.4. Ecological Biotransfer Factors

Table B-4 Ecological Biotransfer Factors

Contaminant	Soil to Plant Biotransfer Constants[1]				Soil to Earthworm Biotransfer Constants[1]				Soil to Small Mammal Biotransfer Constants[1]			
	k_1	k_2	k_3	Reference	k_4	k_5	k_6	Reference	k_4	k_5	k_6	Reference
2,3,4,6-Tetrachlorophenol	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
2-Chlorophenol	2.01	1	0	ORNL 2009	0	1	0	Assumed	0	1	0	Assumed
2,4-Dimethylphenol	1.76	1	0	ORNL 2009	0	1	0	Assumed	0	1	0	Assumed
Acenaphthene	1	0.856	-5.562	USEPA 2009b	1.47	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Acenaphthylene	1	0.791	-1.144	USEPA 2009b	22.9	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Aliphatic $C_{>10}$-C_{12}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aliphatic $C_{>12}$-C_{16}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aliphatic $C_{>16}$-C_{21}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aliphatic $C_{>21}$-C_{34}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aliphatic $C_{>34}$	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aliphatic $C_{>8}$-C_{10}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aliphatic C_6-C_8	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aluminum	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Ammonia	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Anthracene	1	0.778	-0.989	USEPA 2009b	2.42	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Antimony	1	0.938	-3.233	USEPA 2009b	1	1	0	USEPA 2009b	0.05	1	0	USEPA 2009b
Aromatic $C_{>10}$-C_{12}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aromatic $C_{>12}$-C_{16}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aromatic $C_{>16}$-C_{21}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aromatic $C_{>21}$-C_{34}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aromatic $C_{>34}$	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Aromatic $C_{>8}$-C_{10}	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Arsenic	0.038	1	0	USEPA 2009b	1	0.706	-1.421	USEPA 2009b	1	0.819	-4.847	USEPA 2009b
Barium	0.156	1	0	USEPA 2009b	0.091	1	0	USEPA 2009b	0.062	1	0	USEPA 2009b
Benzo[a]anthracene	1	0.594	-2.708	USEPA 2009b	1.59	1	0	USEPA 2009b	0	1	0	USEPA 2009b

Table B-4 Ecological Biotransfer Factors

Contaminant	Soil to Plant Biotransfer Constants[1]				Soil to Earthworm Biotransfer Constants[1]				Soil to Small Mammal Biotransfer Constants[1]			
	k_1	k_2	k_3	Reference	k_4	k_5	k_6	Reference	k_4	k_5	k_6	Reference
Benzene	0	1	0	USEPA 2009b	0	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Benzo[a]pyrene	1	0.975	-2.062	USEPA 2009b	1.33	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Benzo[b,j]fluoranthene	0.310	1	0	USEPA 2009b	2.6	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Benzo[g,h,i]perylene	1	1.183	-0.931	USEPA 2009b	2.94	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Benzo[k]fluoranthene	1	0.860	-2.158	USEPA 2009b	2.6	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Beryllium	1	0.735	-0.536	USEPA 2009b	0.045	1	0	USEPA 2009b	0.05	1	0	USEPA 2009b
Cadmium	1	0.546	-0.475	USEPA 2009b	1	0.795	2.114	USEPA 2009b	1	0.472	-1.257	USEPA 2009b
Chloride	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Chromium (hexavalent)	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Chromium (total)	0.041	1	0	USEPA 2009b	0.306	1	0	USEPA 2009b	1	0.734	-1.46	USEPA 2009b
Chrysene	1	0.594	-2.708	USEPA 2009b	2.29	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Cobalt	0.008	1	0	USEPA 2009b	0.122	1	0	USEPA 2009b	1	1.307	-4.467	USEPA 2009b
Conductivity (dS/m)	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Copper	1	0.394	0.668	USEPA 2009b	0.515	1	0	USEPA 2009b	1	0.144	2.042	USEPA 2009b
Cresol-o	3	1	0	ORNL 2009	0	1	0	Assumed	0	1	0	Assumed
Cresol-m	2.63	1	0	ORNL 2009	0	1	0	Assumed	0	1	0	Assumed
Cresol-p	3	1	0	ORNL 2009	0	1	0	Assumed	0	1	0	Assumed
Cyanide	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
DDT	1	0.752	-2.512	USEPA 2009b	11.2	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Dibenzo[a,h]anthracene	0.68	1	0	USEPA 2009b	2.31	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Dichloromethane	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Dioxin and furans	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Ethylbenzene	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
F1 (C_6-C_{10})	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
F2 ($C_{>10}$-C_{16})	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
F3 ($C_{>16}$-C_{34})	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
F4 ($C_{>34}$)	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed

Table B-4 Ecological Biotransfer Factors

Contaminant	Soil to Plant Biotransfer Constants[1]				Soil to Earthworm Biotransfer Constants[1]				Soil to Small Mammal Biotransfer Constants[1]			
	k_1	k_2	k_3	Reference	k_4	k_5	k_6	Reference	k_4	k_5	k_6	Reference
Fluoranthene	0.5	1	0	USEPA 2009b	3.04	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Fluorene	1	-0.856	-5.562	USEPA 2009b	9.57	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Indeno[1,2,3-c,d]pyrene	0.11	1	0	Travis & Arms 1988	2.86	1	0	-	0	1	0	Assumed
Iron	0	1	0	Assumed	0	1	0	Assumed	1	0.597	-0.288	-
Lead	1	0.561	-1.328	USEPA 2009b	1	0.807	-0.218	USEPA 2009b	1	0.442	0.076	USEPA 2009b
Manganese	0.079	1	0	USEPA 2009b	1	0.682	-0.809	USEPA 2009b	0.021	1	0	USEPA 2009b
Mercury	1	0.544	-0.996	Travis & Arms 1988	1.693	1	0	-	0.024	1	0	-
Molybdenum	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
MTBE	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Naphthalene	12.2	1	0	USEPA 2009b	4.4	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Nickel	1	0.748	-2.223	USEPA 2009b	1.059	1	0	USEPA 2009b	1	0.466	0.246	USEPA 2009b
PCBs (Aroclor 1254)	0.017	1	0	Travis & Arms 1988	1	1.361	1.41	-	7.3	1	0	-
Pentachlorophenol	5.930	1	0	USEPA 2009b	14.63	1	0	USEPA 2009b	0.005	1	0	USEPA 2009b
Phenanthrene	1	0.620	-0.167	USEPA 2009b	1.72	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Phenol	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Pyrene	0.720	1	0	USEPA 2009b	1.75	1	0	USEPA 2009b	0	1	0	USEPA 2009b
Selenium	1	1.104	-0.677	USEPA 2009b	1	0.733	-0.075	USEPA 2009b	1	0.376	-0.416	USEPA 2009b
Silver	0.014	1	0	USEPA 2009b	2.045	1	0	USEPA 2009b	0.004	1	0	USEPA 2009b
Sodium	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Sodium adsorption ratio	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Styrene	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Sulphate	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Tetrachloroethene	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Tetrachloromethane	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Thallium	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Tin	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Toluene	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed

Table B-4 Ecological Biotransfer Factors

Contaminant	Soil to Plant Biotransfer Constants[1]				Soil to Earthworm Biotransfer Constants[1]				Soil to Small Mammal Biotransfer Constants[1]			
	k_1	k_2	k_3	Reference	k_4	k_5	k_6	Reference	k_4	k_5	k_6	Reference
Trichloroethene	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Vinyl Chloride	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Xylenes	0	1	0	Assumed	0	1	0	Assumed	0	1	0	Assumed
Zinc	1	0.554	1.575	USEPA 2009b	1	0.328	4.449	USEPA 2009b	1	0.071	4.363	USEPA 2009b

Notes:

[1] Factors k_1, k_2, k_3, k_4, k_5, and k_6 were derived from published values for use in equations presented in the text.

B.5. Human Toxicity Reference Values

Table B-5 Human Toxicity Reference Values

Contaminant	Non-Carcinogens				Carcinogens					
	Oral tolerable daily intake (mg/kg_{bw}-d)		Inhalation tolerable concentration[1] (mg/kg_{bw}-d)		Oral slope factor (kg_{bw}-d/mg)		Inhalation unit risk (m^3_{air}/mg)		Oral risk specific dose[2] (mg/kg_{bw}-d)	Inhalation risk specific dose[2,3] (mg/kg_{bw}-d)
	Value	Reference	Value	Reference	Value	Reference	Value	Reference		
2,3,4,6-Tetrachlorophenol	1.00E-02	HC 2004b	1.00E-02	AENV 2009a	-	-	-	-	-	-
2-Chlorophenol	5.00E-03	USEPA 2009c	-	-	-	-	-	-	-	-
2,4-Dimethylphenol	2.00E-02	USEPA 2009c	-	-	-	-	-	-	-	-
Acenaphthene	6.00E-02	USEPA 2009c	6.00E-02	AENV 2009a	-	-	-	-	-	-
Acenaphthylene	-	-	-	-	-	-	-	-	-	-
Aliphatic $C_{>10}$-C_{12}	1.00E-01	CCME 2008a	2.23E-01	CCME 2008a	-	-	-	-	-	-
Aliphatic $C_{>12}$-C_{16}	1.00E-01	CCME 2008a	2.23E-01	CCME 2008a	-	-	-	-	-	-
Aliphatic $C_{>16}$-C_{21}	2.00E+00	CCME 2008a	-	-	-	-	-	-	-	-
Aliphatic $C_{>21}$-C_{34}	2.00E+00	CCME 2008a	-	-	-	-	-	-	-	-
Aliphatic $C_{>34}$	2.00E+01	CCME 2008a	-	-	-	-	-	-	-	-
Aliphatic $C_{>8}$-C_{10}	1.00E-01	CCME 2008a	2.23E-01	CCME 2008a	-	-	-	-	-	-
Aliphatic C_6-C_8	5.00E+00	CCME 2008a	4.10E+00	CCME 2008a	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-
Ammonia	-	-	2.23E-02	USEPA 2009c	-	-	-	-	-	-
Anthracene	3.00E-01	USEPA 2009c	3.00E-01	USEPA 2009c	-	-	-	-	-	-
Antimony	4.00E-04	ORNL 2009	-	-	-	-	-	-	-	-
Aromatic $C_{>10}$-C_{12}	4.00E-02	CCME 2008a	4.46E-02	CCME 2008a	-	-	-	-	-	-
Aromatic $C_{>12}$-C_{16}	4.00E-02	CCME 2008a	4.46E-02	CCME 2008a	-	-	-	-	-	-
Aromatic $C_{>16}$-C_{21}	3.00E-02	CCME 2008a	-	-	-	-	-	-	-	-
Aromatic $C_{>21}$-C_{34}	3.00E-02	CCME 2008a	-	-	-	-	-	-	-	-
Aromatic $C_{>34}$	3.00E-02	CCME 2008a	-	-	-	-	-	-	-	-
Aromatic $C_{>8}$-C_{10}	4.00E-02	CCME 2008a	4.46E-02	CCME 2008a	-	-	-	-	-	-
Arsenic	-	-	-	-	2.80E+00	HC 2004b	6.40E+00	HC 2004b	3.57E-06	3.48E-07
Barium	7.00E-02	AENV 2008a	-	-	-	-	-	-	-	-
Benzo[a]anthracene	-	-	-	-	2.30E-01	CCME 2008b[4]	-	-	4.35E-05	-
Benzene	-	-	-	-	3.10E-01	HC 2004b	3.30E-03	HC 2004b	3.23E-05	6.76E-04
Benzo[b,j]fluoranthene	-	-	-	-	2.30E-01	CCME 2008b[4]	-	-	4.35E-05	-

Table B-5 Human Toxicity Reference Values

Contaminant	Non-Carcinogens				Carcinogens					
	Oral tolerable daily intake (mg/kg_{bw}-d)		Inhalation tolerable concentration[1] (mg/kg_{bw}-d)		Oral slope factor (kg_{bw}-d/mg)		Inhalation unit risk (m^3_{air}/mg)		Oral risk specific dose[2] (mg/kg_{bw}-d)	Inhalation risk specific dose[2,3] (mg/kg_{bw}-d)
	Value	Reference	Value	Reference	Value	Reference	Value	Reference		
Benzo[a]pyrene	-	-	-	-	2.30E+00	CCME 2008b	-	-	4.35E-06	-
Benzo[g,h,i]perylene	-	-	-	-	2.30E-02	CCME 2008b[4]	-	-	4.35E-04	-
Benzo[k]fluoranthene	-	-	-	-	2.30E-01	CCME 2008b[4]	-	-	4.35E-05	-
Beryllium	2.00E-03	USEPA 2009c	-	-	-	-	2.40E-03	USEPA 2009c	-	9.29E-04
Cadmium	8.00E-04	HC 2004b	-	-	-	-	9.80E+00	HC 2004b	-	2.28E-07
Chloride	5.10E+01	HC 2006, male adult	-	-	-	-	-	-	-	-
Chromium (hexavalent)	1.00E-03	HC 2004b	-	-	-	-	7.58E+01	HC 2004b	-	2.94E-08
Chromium (total)	1.00E-03	HC 2004b	-	-	-	-	1.09E+01	HC 2004b	-	2.05E-07
Chrysene	-	-	-	-	2.30E-02	CCME 2008b[4]	-	-	4.35E-04	-
Cobalt	-	-	-	-	-	-	-	-	-	-
Conductivity (dS/m)	-	-	-	-	-	-	-	-	-	-
Copper	3.00E-02	HC 2004b	-	-	-	-	-	-	-	-
Cresol-o	5.00E-02	USEPA 2009c	-	-	-	-	-	-	-	-
Cresol-m	5.00E-02	USEPA 2009c	-	-	-	-	-	-	-	-
Cresol-p	5.00E-03	ORNL 2009	-	-	-	-	-	-	-	-
Cyanide	2.00E-02	USEPA 2009c	-	-	-	-	-	-	-	-
DDT	1.00E-02	HC 2004b	-	-	-	-	-	-	-	-
Dibenzo[a,h]anthracene	-	-	-	-	2.30E+00	CCME 2008b[4]	-	-	4.35E-06	-
Dichloromethane	5.00E-02	HC 2004b	6.69E-01	ORNL 2009	7.90E-05	HC 2004b	2.30E-05	HC 2004b	1.27E-01	9.70E-02
Dioxin and furans	2.00E-09	HC 2004b	-	-	-	-	-	-	-	-
Ethylbenzene	1.00E-01	USEPA 2009c	2.23E-01	USEPA 2009c	-	-	-	-	-	-
F1 (C_6-C_{10})	-	-	-	-	-	-	-	-	-	-
F2 ($C_{>10}$-C_{16})	-	-	-	-	-	-	-	-	-	-
F3 ($C_{>16}$-C_{34})	-	-	-	-	-	-	-	-	-	-
F4 ($C_{>34}$)	-	-	-	-	-	-	-	-	-	-
Fluoranthene	4.00E-02	USEPA 2009c	4.00E-02	AENV 2009a	-	-	-	-	-	-
Fluorene	4.00E-02	USEPA 2009c	4.00E-02	AENV 2009a	-	-	-	-	-	-
Indeno[1,2,3-c,d]pyrene	-	-	-	-	2.30E-01	CCME 2008b[4]	-	-	4.35E-05	-

Table B-5 Human Toxicity Reference Values

Contaminant	Non-Carcinogens				Carcinogens					
	Oral tolerable daily intake (mg/kg_{bw}-d)		Inhalation tolerable concentration[1] (mg/kg_{bw}-d)		Oral slope factor (kg_{bw}-d/mg)		Inhalation unit risk (m^3_{air}/mg)		Oral risk specific dose[2] (mg/kg_{bw}-d)	Inhalation risk specific dose[2,3] (mg/kg_{bw}-d)
	Value	Reference	Value	Reference	Value	Reference	Value	Reference		
Iron	6.40E-01	HC 2006, male adult	-	-	-	-	-	-	-	-
Lead	3.60E-03	HC 2004b	-	-	-	-	-	-	-	-
Manganese	1.50E-01	HC 2006, 14-18 yr. male	-	-	-	-	-	-	-	-
Mercury	3.00E-04	HC 2004b	-	-	-	-	-	-	-	-
Molybdenum	2.50E-02	HC 2006, 1-3 yr. child	-	-	-	-	-	-	-	-
MTBE	1.00E-02	HC 2004b	3.70E-02	HC 2004b	-	-	-	-	-	-
Naphthalene	2.00E-02	USEPA 2009c	6.69E-04	USEPA 2009c	-	-	-	-	-	-
Nickel	-	-	1.80E-05	HC 2004b	-	-	-	-	-	-
PCBs (Aroclor 1254)	1.00E-03	HC 2004b	-	-	-	-	-	-	-	-
Pentachlorophenol	6.00E-03	HC 2004b	6.00E-03	AENV 2009a	-	-	-	-	-	-
Phenanthrene	-	-	-	-	-	-	-	-	-	-
Phenol	6.00E-02	HC 2004b	6.00E-02	AENV 2009a	-	-	-	-	-	-
Pyrene	3.00E-02	USEPA 2009c	3.00E-02	AENV 2009a	-	-	-	-	-	-
Selenium	6.20E-03	CCME 2009	-	-	-	-	-	-	-	-
Silver	5.00E-03	USEPA 2009c	-	-	-	-	-	-	-	-
Sodium	3.30E+01	HC 2006, adult	-	-	-	-	-	-	-	-
Sodium adsorption ratio	-	-	-	-	-	-	-	-	-	-
Styrene	1.20E-01	HC 2004b	2.05E-02	HC 2004b	-	-	-	-	-	-
Sulphate	-	-	-	-	-	-	-	-	-	-
Tetrachloroethene	1.40E-02	HC 2004b	8.03E-02	HC 2004b	-	-	-	-	-	-
Tetrachloromethane	7.00E-04	USEPA 2009c	7.00E-04	AENV 2009a	1.30E-01	USEPA 2009c	1.50E-02	USEPA 2009c	7.69E-05	1.49E-04
Thallium	7.00E-05	CCME 2009	-	-	-	-	-	-	-	-
Tin	-	-	-	-	-	-	-	-	-	-

Table B-5 Human Toxicity Reference Values

Contaminant	Non-Carcinogens				Carcinogens					
	Oral tolerable daily intake (mg/kg_{bw}-d)		Inhalation tolerable concentration[1] (mg/kg_{bw}-d)		Oral slope factor (kg_{bw}-d/mg)		Inhalation unit risk (m^3_{air}/mg)		Oral risk specific dose[2] (mg/kg_{bw}-d)	Inhalation risk specific dose[2,3] (mg/kg_{bw}-d)
	Value	Reference	Value	Reference	Value	Reference	Value	Reference		
Toluene	2.20E-01	HC 2004b	8.47E-01	HC 2004b	-	-	-	-	-	-
Trichloroethene	1.46E-03	CCME 2009	8.92E-03	CCME 2009	2.50E-04	CCME 2009	6.10E-04	CCME 2009	4.00E-02	3.66E-03
Vinyl Chloride	3.00E-03	USEPA 2009c	2.23E-02	AENV 2009a	2.60E-01	HC 2004b	8.80E-03	USEPA 2009c	3.85E-05	2.53E-04
Xylenes	1.50E+00	HC 2004b	4.01E-02	HC 2004b	-	-	-	-	-	-
Zinc	5.60E-01	HC 2006, 7-12 mo. infant	-	-	-	-	-	-	-	-

Notes:

[1] Where value were presented as mg/m^3_{air} in the referenced document, they were converted to mg/kg_{bw}/d using adult inhalation rate and body weight.

[2] Calculated using an allowable risk level of 1×10^{-5} as per HC (2004a).

[3] Converted from mg/m^3_{air} to mg/kg-d by multiplying by adult inhalation rate and divided by adult body weight.

[4] This values have been multiplied by its potency equivalence factors relative to benzo[a]pyrene (AENV 2009a).

B.6. Ecological Toxicity Reference Values: Plants, Invertebrates, & Microbes

Table B-6 Ecological Toxicity Reference Values: Plants, Invertebrates, & Microbes

Contaminant	Terrestrial Plants & Soil Invertebrates								Soil Microorganisms (mg/kg_{soil})		
	Fine Grained Soil (mg/kg_{soil})			Coarse Grained Soil (mg/kg_{soil})			Irrigation Water (mg/L_{water})		Threshold effects value	Low effects value	Reference
	Threshold effects value	Low effects value	Reference	Threshold effects value	Low effects value	Reference	Value	Reference			
2,3,4,6-Tetrachlorophenol	-	-	-	-	-	-	-	-	-	-	-
2-Chlorophenol	-	-	-	-	-	-	-	-	-	-	-
Acenaphthene	-	-	-	-	-	-	-	-	-	-	-
Acenaphthylene	-	-	-	-	-	-	-	-	-	-	-
Aliphatic $C_{>10}$-C_{12}	-	-	-	-	-	-	-	-	-	-	-
Aliphatic $C_{>12}$-C_{16}	-	-	-	-	-	-	-	-	-	-	-
Aliphatic $C_{>8}$-C_{10}	-	-	-	-	-	-	-	-	-	-	-
Aliphatic C_6-C_8	-	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	5	AENV 2009a,b	-	-	-
Ammonia	-	-	-	-	-	-	-	-	-	-	-
Anthracene	2.5	32	AENV 2009a,b	2.5	32	AENV 2009a,b	-	-	-	-	-
Antimony	20	40	AENV 2009a,b	20	40	AENV 2009a,b	-	-	-	-	-
Aromatic $C_{>10}$-C_{12}	-	-	-	-	-	-	-	-	-	-	-
Aromatic $C_{>12}$-C_{16}	-	-	-	-	-	-	-	-	-	-	-
Aromatic $C_{>8}$-C_{10}	-	-	-	-	-	-	-	-	-	-	-
Arsenic	17	26	AENV 2009a,b	17	26	AENV 2009a,b	0.1	AENV 2009a,b	-	-	-
Barium	750	2000	AENV 2009a,b	750	2000	AENV 2009a,b	-	-	-	-	-
Benzo[a]anthracene	-	-	-	-	-	-	-	-	-	-	-
Benzene	60	310	AENV 2009a,b	31	180	AENV 2009a,b	-	-	-	-	-
Benzo[b,j]fluoranthene	-	-	-	-	-	-	-	-	-	-	-
Benzo[a]pyrene	20	72	AENV 2009a,b	20	72	AENV 2009a,b	-	-	-	-	-
Benzo[g,h,i]perylene	-	-	-	-	-	-	-	-	-	-	-
Benzo[k]fluoranthene	-	-	-	-	-	-	-	-	-	-	-
Beryllium	5	8	AENV 2009a,b	5	8	AENV 2009a,b	-	-	-	-	-
Cadmium	10	22	AENV 2009a,b	10	22	AENV 2009a,b	0.0051	AENV 2009a,b	54	195	AENV 2009a,b
Chloride	-	-	-	-	-	-	100	AENV 2009a,b	-	-	-
Chromium (hexavalent)	0.4	1.4	AENV 2009a,b	0.4	1.4	AENV 2009a,b	-	-	-	-	-
Chromium (total)	64	87	AENV 2009a,b	64	87	AENV 2009a,b	0.0049	AENV 2009a,b	52	-	AENV 2009a,b
Chrysene	-	-	-	-	-	-	-	-	-	-	-

Table B-6 Ecological Toxicity Reference Values: Plants, Invertebrates, & Microbes

Contaminant	Terrestrial Plants & Soil Invertebrates								Soil Microorganisms (mg/kg_{soil})		
	Fine Grained Soil (mg/kg_{soil})			Coarse Grained Soil (mg/kg_{soil})			Irrigation Water (mg/L_{water})		Threshold effects value	Low effects value	Reference
	Threshold effects value	Low effects value	Reference	Threshold effects value	Low effects value	Reference	Value	Reference			
Cobalt	20	300	AENV 2009a,b	20	300	AENV 2009a,b	-	-	-	-	-
Conductivity (dS/m)	2	4	AENV 2009a,b	2	4	AENV 2009a,b	-	-	-	-	-
Copper	63	91	AENV 2009a,b	63	91	AENV 2009a,b	0.2	AENV 2009a,b	350	350	AENV 2009a,b
Cresol-o	-	-	-	-	-	-	-	-	-	-	-
Cresol-m	-	-	-	-	-	-	-	-	-	-	-
Cresol-p	-	-	-	-	-	-	-	-	-	-	-
Cyanide	0.9	8	AENV 2009a,b	0.9	8	AENV 2009a,b	-	-	-	-	-
DDT	12	12	AENV 2009a,b	12	12	AENV 2009a,b	-	-	547	547	AENV 2009a,b
Dibenzo[a,h]anthracene	-	-	-	-	-	-	-	-	-	-	-
Dichloromethane	-	-	-	-	-	-	-	-	-	-	-
Dioxin and furans	-	-	-	-	-	-	-	-	-	-	-
Ethylbenzene	120	430	AENV 2009a,b	55	300	AENV 2009a,b	-	-	-	-	-
F1 (C_6-C_{10})	210	320	AENV 2009a,b	210	320	AENV 2009a,b	-	-	-	-	-
F2 ($C_{>10}$-C_{16})	150	260	AENV 2009a,b	150	260	AENV 2009a,b	-	-	-	-	-
F3 ($C_{>16}$-C_{34})	1300	2500	AENV 2009a,b	300	1700	AENV 2009a,b	-	-	-	-	-
F4 ($C_{>34}$)	5600	6600	AENV 2009a,b	2800	3300	AENV 2009a,b	-	-	-	-	-
Fluoranthene	50	180	AENV 2009a,b	50	180	AENV 2009a,b	-	-	-	-	-
Fluorene	-	-	-	-	-	-	-	-	-	-	-
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	5	AENV 2009a,b	-	-	-
Lead	300	600	AENV 2009a,b	300	600	AENV 2009a,b	0.2	AENV 2009a,b	723	834	AENV 2009a,b
Manganese	-	-	-	-	-	-	0.2	AENV 2009a,b	-	-	-
Mercury	12	50	AENV 2009a,b	12	50	AENV 2009a,b	-	-	20	52	AENV 2009a,b
Molybdenum	4	40	AENV 2009a,b	4	40	AENV 2009a,b	-	-	-	-	-
MTBE	-	-	-	-	-	-	-	-	-	-	-
Naphthalene	-	-	-	-	-	-	-	-	-	-	-
Nickel	50	50	AENV 2009a,b	50	50	AENV 2009a,b	0.2	AENV 2009a,b	146	182	AENV 2009a,b
PCBs (Aroclor 1254)	33	33	AENV 2009a,b	33	33	AENV 2009a,b	-	-	-	-	-

Table B-6 Ecological Toxicity Reference Values: Plants, Invertebrates, & Microbes

Contaminant	Terrestrial Plants & Soil Invertebrates								Soil Microorganisms (mg/kg_{soil})		
	Fine Grained Soil (mg/kg_{soil})			Coarse Grained Soil (mg/kg_{soil})			Irrigation Water (mg/L_{water})		Threshold effects value	Low effects value	Reference
	Threshold effects value	Low effects value	Reference	Threshold effects value	Low effects value	Reference	Value	Reference			
Pentachlorophenol	11	28	AENV 2009a,b	11	28	AENV 2009a,b	-	-	-	-	-
Phenanthrene	-	-	-	-	-	-	-	-	-	-	-
Phenol	20	130	AENV 2009a,b	20	130	AENV 2009a,b	-	-	-	-	-
Pyrene	-	-	-	-	-	-	-	-	-	-	-
Selenium	1	2.9	AENV 2009a,b	1	2.9	AENV 2009a,b	0.02	AENV 2009a,b	-	-	-
Silver	20	40	AENV 2009a,b	20	40	AENV 2009a,b	0.02	AENV 2009a,b	-	-	-
Sodium adsorption ratio	5	12	AENV 2009a,b	5	12	AENV 2009a,b	-	-	-	-	-
Styrene	-	-	-	-	-	-	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-	-	-	-	-	-	-
Tetrachloromethane	-	-	-	-	-	-	-	-	-	-	-
Thallium	1.4	3.6	AENV 2009a,b	1.4	3.6	AENV 2009a,b	-	-	-	-	-
Tin	5	300	AENV 2009a,b	5	300	AENV 2009a,b	-	-	-	-	-
Toluene	110	330	AENV 2009a,b	75	250	AENV 2009a,b	-	-	-	-	-
Trichloroethene	3	50	AENV 2009a,b	3	50	AENV 2009a,b	-	-	-	-	-
Xylenes	65	230	AENV 2009a,b	95	350	AENV 2009a,b	-	-	-	-	-
Zinc	200	360	AENV 2009a,b	200	360	AENV 2009a,b	1	AENV 2009a,b	200	320	AENV 2009a,b

B.7. Ecological Toxicity Reference Values: Voles, Shrews, Kestrel, & Aquatic Life

Table B-7 Ecological Toxicity Reference Values: Voles, Shrews, Kestrel, & Aquatic Life

Contaminant	Animal						Aquatic Life			
	Primary consumer (mg/kg_{bw}-d)		Secondary consumer (mg/kg_{bw}-d)		Tertiary consumer (mg/kg_{bw}-d)		Water (mg/L_{water})		Freshwater sediment (mg/kg_{sed})	
	Value	Reference	Value	Reference	Value	Reference	Value	Reference	Value	Reference
2,3,4,6-Tetrachlorophenol	-	-	-	-	-	-	0.001	AENV 2009a	-	-
2-Chlorophenol	-	-	-	-	-	-	0.007	CCME 2009	-	-
Acenaphthene	70	AENV 2009a,b	70	AENV 2009a,b	70	AENV 2009a,b	0.0058	CCME 2009	0.00671	CCME 2009
Acenaphthylene	-	-	-	-	-	-	0.046	CCME 2008b	0.00587	CCME 2009
Aliphatic $C_{>10}$-C_{12}	-	-	-	-	-	-	0.00118	AENV 2009a	-	-
Aliphatic $C_{>12}$-C_{16}	-	-	-	-	-	-	7.4E-05	AENV 2009a	-	-
Aliphatic $C_{>8}$-C_{10}	-	-	-	-	-	-	0.0076	AENV 2009a	-	-
Aliphatic C_6-C_8	-	-	-	-	-	-	0.0465	AENV 2009a	-	-
Aluminum	-	-	-	-	-	-	0.1	CCME 2009	-	-
Ammonia	-	-	-	-	-	-	3.26	CCME 2009	-	-
Anthracene	200	AENV 2009a,b	200	AENV 2009a,b	200	AENV 2009a,b	1.2E-05	CCME 2009	0.0469	CCME 2009
Antimony	0.059	USEPA 2009b, vole	0.059	USEPA 2009b, shrew	0.059	USEPA 2009b, weasel	-	-	-	-
Aromatic $C_{>10}$-C_{12}	-	-	-	-	-	-	0.096	AENV 2009a	-	-
Aromatic $C_{>12}$-C_{16}	-	-	-	-	-	-	0.0554	AENV 2009a	-	-
Aromatic $C_{>8}$-C_{10}	-	-	-	-	-	-	0.14	AENV 2009a	-	-
Arsenic	1.04	USEPA 2009b, vole	1.04	USEPA 2009b, shrew	2.24	USEPA 2009b, hawk	0.005	CCME 2009	5.9	CCME 2009
Barium	15	AENV 2004	15	AENV 2004	15	AENV 2004	-	-	-	-
Benzo[a]anthracene	20	AENV 2009a,b	20	AENV 2009a,b	20	AENV 2009a,b	1.8E-05	CCME 2009	0.0317	CCME 2009
Benzene	0.08	AENV 2009a,b	0.08	AENV 2009a,b	0.08	AENV 2009a,b	0.37	CCME 2009	-	-
Benzo[b,j]fluoranthene	20	AENV 2009a,b	20	AENV 2009a,b	20	AENV 2009a,b	0.00048	AENV 2009a	-	-
Benzo[a]pyrene	2	AENV 2009a,b	2	AENV 2009a,b	2	AENV 2009a,b	1.5E-05	CCME 2009	0.0319	CCME 2009
Benzo[g,h,i]perylene	-	-	-	-	-	-	0.00017	AENV 2009a	-	-
Benzo[k]fluoranthene	20	AENV 2009a,b	20	AENV 2009a,b	20	AENV 2009a,b	0.00048	AENV 2009a	-	-
Beryllium	0.532	USEPA 2009b, vole	0.532	USEPA 2009b, shrew	0.532	USEPA 2009b, weasel	-	-	-	-
Cadmium	0.456	CCME 2009	0.456	CCME 2009	0.456	CCME 2009	1.7E-05	CCME 2009	0.6	CCME 2009
Chloride	-	-	-	-	-	-	230	AENV 2009a	-	-
Chromium (hexavalent)	9.24	USEPA 2009b, vole	9.24	USEPA 2009b, shrew	2.66	USEPA 2009b, hawk	0.001	CCME 2009	-	-
Chromium (total)	2.4	USEPA 2009b, vole	2.4	USEPA 2009b, shrew	2.4	USEPA 2009b, weasel	0.0089	CCME 2009	37.3	CCME 2009
Chrysene	20	AENV 2009a,b	20	AENV 2009a,b	20	AENV 2009a,b	0.0014	CCME 2008b	0.0571	CCME 2009

Table B-7 Ecological Toxicity Reference Values: Voles, Shrews, Kestrel, & Aquatic Life

Contaminant	Animal						Aquatic Life			
	Primary consumer (mg/kg_{bw}-d)		Secondary consumer (mg/kg_{bw}-d)		Tertiary consumer (mg/kg_{bw}-d)		Water (mg/L_{water})		Freshwater sediment (mg/kg_{sed})	
	Value	Reference	Value	Reference	Value	Reference	Value	Reference	Value	Reference
Cobalt	7.33	USEPA 2009b, vole	7.33	USEPA 2009b, shrew	7.61	USEPA 2009b, hawk	-	-	-	-
Conductivity (dS/m)	-	-	-	-	-	-	-	-	-	-
Copper	5.6	USEPA 2009b, vole	5.6	USEPA 2009b, shrew	4.05	USEPA 2009b, hawk	0.004	CCME 2009	35.7	CCME 2009
Cresol-o	-	-	-	-	-	-	0.004	CCME 2009	-	-
Cresol-m	-	-	-	-	-	-	0.004	CCME 2009	-	-
Cresol-p	-	-	-	-	-	-	0.004	CCME 2009	-	-
Cyanide	0.315	CCME 2009	0.315	CCME 2009	0.315	CCME 2009	0.005	CCME 2009	-	-
DDT	0.37	CCME 2009	0.37	CCME 2009	0.37	CCME 2009	-	-	0.00119	CCME 2009
Dibenzo[a,h]anthracene	-	-	-	-	-	-	0.00026	CCME 2008b	0.00622	CCME 2009
Dichloromethane	-	-	-	-	-	-	0.0981	CCME 2009	-	-
Dioxin and furans	-	-	-	-	-	-	-	-	8.5E-07	CCME 2009
Ethylbenzene	2.91	AENV 2009a,b	2.91	AENV 2009a,b	2.91	AENV 2009a,b	0.09	CCME 2009	-	-
F1 (C_6-C_{10})	48.72	AENV 2009a,b	48.72	AENV 2009a,b	48.72	AENV 2009a,b	-	-	-	-
F2 ($C_{>10}$-C_{16})	44.73	AENV 2009a,b	44.73	AENV 2009a,b	44.73	AENV 2009a,b	-	-	-	-
F3 ($C_{>16}$-C_{34})	72.45	AENV 2009a,b	72.45	AENV 2009a,b	72.45	AENV 2009a,b	-	-	-	-
F4 ($C_{>34}$)	38.22	AENV 2009a,b	38.22	AENV 2009a,b	38.22	AENV 2009a,b	-	-	-	-
Fluoranthene	50	AENV 2009a,b	50	AENV 2009a,b	50	AENV 2009a,b	0.00004	CCME 2009	0.111	CCME 2009
Fluorene	50	AENV 2009a,b	50	AENV 2009a,b	50	AENV 2009a,b	0.003	CCME 2009	0.0212	CCME 2009
Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	-	0.00021	CCME 2008b	-	-
Iron	-	-	-	-	-	-	0.3	CCME 2009	-	-
Lead	1.8	CCME 2009	1.8	CCME 2009	1.8	CCME 2009	0.002	CCME 2009	35	CCME 2009
Manganese	51.5	USEPA 2009b, vole	51.5	USEPA 2009b, shrew	179	USEPA 2009b, hawk	-	-	-	-
Mercury	-	-	-	-	-	-	2.6E-05	CCME 2009	0.17	CCME 2009
Molybdenum	-	-	-	-	-	-	0.073	CCME 2009	-	-
MTBE	-	-	-	-	-	-	10	CCME 2009	-	-
Naphthalene	28.6	AENV 2009a,b	28.6	AENV 2009a,b	28.6	AENV 2009a,b	0.0011	CCME 2009	0.0346	CCME 2009
Nickel	25	CCME 2009	25	CCME 2009	25	CCME 2009	0.065	CCME 2009	-	-
PCBs (Aroclor 1254)	0.34	CCME 2009	0.68	CCME 2009	0.87	CCME 2009	-	-	0.0341	CCME 2009
Pentachlorophenol	8.42	USEPA 2009b, vole	8.42	USEPA 2009b, shrew	6.73	USEPA 2009b, hawk	0.0005	CCME 2009	-	-

Table B-7 Ecological Toxicity Reference Values: Voles, Shrews, Kestrel, & Aquatic Life

Contaminant	Animal						Aquatic Life			
	Primary consumer (mg/kg_{bw}-d)		Secondary consumer (mg/kg_{bw}-d)		Tertiary consumer (mg/kg_{bw}-d)		Water (mg/L_{water})		Freshwater sediment (mg/kg_{sed})	
	Value	Reference	Value	Reference	Value	Reference	Value	Reference	Value	Reference
Phenanthrene	140	AENV 2009a,b	140	AENV 2009a,b	140	AENV 2009a,b	0.0004	CCME 2009	0.0419	CCME 2009
Phenol	-	-	-	-	-	-	0.004	CCME 2009	-	-
Pyrene	25	AENV 2009a,b	25	AENV 2009a,b	25	AENV 2009a,b	2.5E-05	CCME 2009	0.053	CCME 2009
Selenium	0.3	CCME 2009	0.3	CCME 2009	0.3	CCME 2009	0.001	CCME 2009	-	-
Silver	6.02	USEPA 2009b, vole	6.02	USEPA 2009b, shrew	2.02	USEPA 2009b, hawk	0.0001	CCME 2009	-	-
Sodium adsorption ratio	-	-	-	-	-	-	-	-	-	-
Styrene	-	-	-	-	-	-	0.072	CCME 2009	-	-
Tetrachloroethene	-	-	-	-	-	-	0.111	AENV 2009a	-	-
Tetrachloromethane	-	-	-	-	-	-	0.0133	CCME 2009	-	-
Thallium	0.03	CCME 2009	0.03	CCME 2009	0.03	CCME 2009	0.0008	CCME 2009	-	-
Tin	-	-	-	-	-	-	-	-	-	-
Toluene	4.46	AENV 2009a,b	4.46	AENV 2009a,b	4.46	AENV 2009a,b	0.002	CCME 2009	-	-
Trichloroethene	-	-	-	-	-	-	0.021	AENV 2009a	-	-
Xylenes	11.9	AENV 2009a,b	11.9	AENV 2009a,b	11.9	AENV 2009a,b	0.18	AENV 2009a	-	-
Zinc	10	CCME 2009	10	CCME 2009	10	CCME 2009	0.03	CCME 2009	123	CCME 2009

B.8. Contaminant Concentration Ranges

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
1	Acenaphthene	9.0E-2	1.0E-1	1.1E-1	1.0E-2	1.6E+0	1.5E+1	1.3E-1	1.5E-1	1.6E-1	1.0E-5	1.0E-5	1.0E-5	1.0E-5	7.5E-5	1.4E-4	2.4E-1	6.5E-1	1.3E+0
1	Acenaphthylene	1.3E-1	1.5E-1	1.7E-1	3.0E-2	2.1E-1	1.3E+0	2.0E-2	1.1E-1	1.5E-1	-	-	-	-	-	-	1.4E-1	2.4E-1	3.2E-1
1	Aliphatic C>10-C12	-	-	-	2.1E+1	2.8E+2	5.4E+2	-	-	-	-	-	-	-	-	-	1.4E+1	1.8E+1	2.7E+1
1	Aliphatic C>12-C16	-	-	-	2.5E+1	3.4E+2	6.6E+2	-	-	-	-	-	-	-	-	-	1.7E+1	2.2E+1	3.3E+1
1	Aliphatic C>16-C21	1.6E+2	1.6E+2	1.6E+2	3.4E+1	9.5E+2	3.6E+3	3.8E+2	3.8E+2	3.8E+2	-	-	-	-	-	-	8.6E+1	3.8E+2	8.1E+2
1	Aliphatic C>21-C34	6.8E+1	6.9E+1	6.9E+1	1.4E+1	4.1E+2	1.6E+3	1.6E+2	1.6E+2	1.6E+2	-	-	-	-	-	-	3.7E+1	1.6E+2	3.5E+2
1	Aliphatic C>34	1.7E+2	2.0E+2	2.4E+2	2.0E+2	2.9E+2	4.5E+2	3.7E+2	3.7E+2	3.7E+2	-	-	-	-	-	-	1.0E+2	3.4E+2	7.0E+2
1	Aluminum	1.3E+4	1.7E+4	2.2E+4	9.8E+3	1.7E+4	2.4E+4	2.0E+4	2.2E+4	2.4E+4	8.7E-2	8.7E-2	8.7E-2	2.2E-1	4.8E-1	8.0E-1	2.0E+2	4.5E+3	1.7E+4
1	Anthracene	2.1E-1	3.3E-1	4.4E-1	1.0E-2	1.6E+0	1.1E+1	3.0E-2	2.0E-1	3.1E-1	-	-	-	1.0E-5	1.2E-5	2.0E-5	5.8E-1	7.4E-1	9.5E-1
1	Antimony	-	-	-	2.0E-1	1.1E+1	2.2E+1	-	-	-	-	-	-	-	-	-	2.0E+0	2.9E+0	3.0E+0
1	Aromatic C>10-C12	-	-	-	5.0E+0	7.0E+1	1.4E+2	-	-	-	-	-	-	-	-	-	3.5E+0	4.7E+0	7.0E+0
1	Aromatic C>12-C16	-	-	-	6.0E+0	8.6E+1	1.7E+2	-	-	-	-	-	-	-	-	-	4.0E+0	5.3E+0	8.0E+0
1	Aromatic C>16-C21	3.9E+1	4.0E+1	4.0E+1	8.0E+0	2.4E+2	9.1E+2	9.4E+1	9.4E+1	9.4E+1	-	-	-	-	-	-	1.5E+0	1.4E+1	4.3E+1
1	Aromatic C>21-C34	1.7E+1	1.7E+1	1.7E+1	4.0E+0	1.0E+2	3.9E+2	4.0E+1	4.0E+1	4.0E+1	-	-	-	-	-	-	9.0E+0	4.0E+1	8.7E+1
1	Aromatic C>34	4.1E+1	5.0E+1	5.9E+1	5.0E+1	7.7E+1	1.1E+2	-	-	-	-	-	-	-	-	-	2.6E+1	8.6E+1	1.8E+2
1	Arsenic	-	-	-	4.0E+0	1.3E+1	2.1E+1	-	-	-	3.0E-3	3.0E-3	3.0E-3	5.0E-4	6.0E-4	1.0E-3	6.0E+0	6.6E+0	7.0E+0
1	Benzene	-	-	-	3.2E-2	6.0E-2	9.9E-2	9.0E-3	9.0E-3	9.0E-3	-	-	-	-	-	-	4.5E-3	6.8E-3	9.0E-3
1	Benzo[a]anthracene	2.0E-2	5.2E-1	1.0E+0	1.0E-2	1.5E+0	1.3E+1	1.0E-1	3.4E-1	5.9E-1	-	-	-	-	-	-	1.1E+0	1.8E+0	2.4E+0
1	Benzo[a]pyrene	2.0E-2	5.9E-1	1.1E+0	2.0E-2	1.0E+0	7.4E+0	1.1E-1	3.0E-1	5.5E-1	-	-	-	-	-	-	1.2E+0	1.8E+0	2.3E+0
1	Benzo[b,j]fluoranthene	1.0E-2	4.9E-1	8.8E-1	2.0E-2	1.9E+0	1.6E+1	9.0E-2	3.7E-1	6.9E-1	-	-	-	-	-	-	1.0E+0	2.2E+0	2.9E+0
1	Benzo[g,h,i]perylene	4.3E-1	5.2E-1	6.0E-1	1.0E-2	1.3E+0	1.5E+1	7.0E-2	2.4E-1	3.5E-1	-	-	-	-	-	-	7.1E-1	1.1E+0	1.4E+0
1	Benzo[k]fluoranthene	1.0E-2	4.3E-1	7.9E-1	2.0E-2	1.8E-1	5.6E-1	8.0E-2	1.8E-1	2.8E-1	-	-	-	-	-	-	4.6E-1	7.7E-1	9.1E-1
1	Cadmium	-	-	-	4.0E-2	1.1E-1	1.6E-1	3.3E-1	3.3E-1	3.3E-1	7.9E-4	7.9E-4	7.9E-4	3.0E-5	3.6E-5	6.0E-5	9.0E-2	2.4E-1	3.5E-1
1	Chromium (total)	-	-	-	1.4E+2	1.4E+2	1.4E+2	-	-	-	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.4E-3	2.0E-3	4.0E+0	7.7E+0	1.2E+1
1	Chrysene	2.0E-2	6.2E-1	1.2E+0	5.0E-2	2.1E+0	2.2E+1	1.1E-1	3.4E-1	5.6E-1	-	-	-	-	-	-	1.2E+0	1.8E+0	2.4E+0
1	Copper	4.9E+1	5.5E+1	6.0E+1	6.0E+0	9.8E+1	2.8E+2	-	-	-	-	-	-	1.2E-3	1.5E-2	2.0E-2	1.3E+2	1.9E+2	2.9E+2
1	Dibenzo[a,h]anthracene	1.0E-1	1.3E-1	1.5E-1	3.0E-2	1.5E-1	1.0E+0	3.0E-2	6.0E-2	9.0E-2	-	-	-	-	-	-	1.8E-1	2.7E-1	3.3E-1
1	Ethylbenzene	2.0E-2	2.0E-2	2.0E-2	1.0E-2	2.5E-2	3.8E-2	-	-	-	-	-	-	-	-	-	-	-	-
1	F2 (C>10-C16)	-	-	-	5.7E+1	7.8E+2	1.5E+3	-	-	-	-	-	-	-	-	-	3.8E+1	5.0E+1	7.5E+1
1	F3 (C>16-C34)	2.8E+2	2.9E+2	2.9E+2	6.0E+1	1.7E+3	6.5E+3	6.7E+2	6.7E+2	6.7E+2	-	-	-	-	-	-	1.5E+2	6.7E+2	1.5E+3
1	F4 (C>34)	1.3E+2	1.5E+2	2.5E+2	1.5E+2	3.0E+2	4.6E+2	9.3E+1	3.2E+2	5.6E+2	3.7E+2	3.7E+2	3.7E+2	-	-	-	1.3E+2	4.3E+2	8.8E+2
1	Fluoranthene	4.0E-2	1.1E+0	2.1E+0	3.0E-2	5.5E+0	4.9E+1	2.1E-1	9.0E-1	1.3E+0	-	-	-	2.0E-5	2.4E-5	4.0E-5	2.2E+0	3.4E+0	4.5E+0
1	Fluorene	1.0E-1	1.5E-1	1.9E-1	1.0E-2	1.3E+0	1.3E+1	1.8E-1	1.9E-1	1.9E-1	2.0E-5	2.0E-5	2.0E-5	4.0E-2	4.8E-2	8.0E-2	3.0E-1	6.6E-1	1.3E+0
1	Indeno[1,2,3-c,d]pyrene	4.4E-1	5.3E-1	6.2E-1	1.0E-2	5.6E-1	4.0E+0	7.0E-2	2.0E-1	3.6E-1	-	-	-	-	-	-	7.3E-1	1.1E+0	1.5E+0
1	Iron	2.1E+4	2.6E+4	3.3E+4	2.0E+4	2.8E+4	3.7E+4	2.9E+4	3.2E+4	3.7E+4	1.2E+0	1.2E+0	1.2E+0	2.8E-1	2.1E+0	4.3E+0	5.0E+3	5.8E+3	7.4E+3

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
1	Lead	9.0E+0	1.0E+2	2.2E+2	2.0E+0	1.9E+2	1.8E+3	1.0E+1	3.6E+1	7.0E+1	5.0E-4	5.0E-4	5.0E-4	6.0E-4	3.0E-3	6.0E-3	1.1E+2	2.1E+2	2.9E+2
1	Mercury	6.0E-2	4.2E-1	1.5E+0	5.0E-2	8.7E-1	8.4E+0	9.0E-2	7.2E-1	1.4E+0	-	-	-	2.0E-5	3.7E-5	6.0E-5	9.3E-1	1.2E+0	1.7E+0
1	Naphthalene	3.0E-2	1.3E-1	2.2E-1	1.0E-2	7.3E-1	3.9E+0	2.0E-2	4.7E-1	1.3E+0	9.0E-5	9.0E-5	9.0E-5	2.0E-5	1.6E-4	3.0E-4	3.8E-1	6.1E-1	7.9E-1
1	Nickel	-	-	-	2.2E+1	2.3E+1	2.3E+1	-	-	-	4.6E-2	4.6E-2	4.6E-2	-	-	-	7.0E+0	1.1E+1	1.5E+1
1	PCBs (Aroclor 1254)	-	-	-	8.0E-2	1.7E-1	2.8E-1	-	-	-	-	-	-	-	-	-	-	-	-
1	Phenanthrene	5.0E-2	6.6E-1	1.3E+0	2.0E-2	5.0E+0	4.3E+1	1.0E-1	8.0E-1	1.2E+0	2.0E-5	2.0E-5	2.0E-5	1.0E-5	4.0E-5	7.0E-5	1.5E+0	2.7E+0	3.3E+0
1	Pyrene	4.0E-2	1.1E+0	2.1E+0	3.0E-2	4.1E+0	3.5E+1	2.1E-1	9.0E-1	1.4E+0	-	-	-	1.5E-2	1.8E-2	3.0E-2	2.2E+0	3.4E+0	4.2E+0
1	Tin	8.0E+0	3.7E+1	6.3E+1	1.0E+0	1.1E+1	7.4E+1	2.0E+0	2.0E+0	2.0E+0	-	-	-	-	-	-	1.3E+1	1.5E+1	1.7E+1
1	Toluene	-	-	-	-	-	-	-	-	-	7.0E-4	7.0E-4	7.0E-4	-	-	-	-	-	-
1	Xylenes	-	-	-	5.0E-2	9.1E+0	2.7E+1	-	-	-	-	-	-	-	-	-	-	-	-
1	Zinc	7.0E+0	8.2E+1	1.5E+2	1.6E+1	9.4E+1	2.0E+2	1.4E+1	3.6E+1	5.7E+1	-	-	-	1.1E-2	1.3E-2	2.1E-2	1.2E+2	1.6E+2	2.0E+2
2	Aliphatic C>10-C12	3.1E+2	3.1E+2	3.1E+2	3.1E+2	3.1E+2	3.1E+2	-	-	-	-	-	-	-	-	-	-	-	-
2	Aliphatic C>12-C16	3.8E+2	3.8E+2	3.8E+2	3.8E+2	3.8E+2	3.8E+2	-	-	-	-	-	-	-	-	-	-	-	-
2	Aliphatic C>16-C21	1.3E+4	1.3E+4	1.3E+4	1.3E+4	1.3E+4	1.3E+4	-	-	-	-	-	-	-	-	-	-	-	-
2	Aliphatic C>21-C34	5.8E+3	5.8E+3	5.8E+3	5.8E+3	5.8E+3	5.8E+3	-	-	-	-	-	-	-	-	-	-	-	-
2	Aromatic C>10-C12	7.7E+1	7.7E+1	7.7E+1	7.7E+1	7.7E+1	7.7E+1	-	-	-	-	-	-	-	-	-	-	-	-
2	Aromatic C>12-C16	9.5E+1	9.5E+1	9.5E+1	9.5E+1	9.5E+1	9.5E+1	-	-	-	-	-	-	-	-	-	-	-	-
2	Aromatic C>16-C21	3.4E+3	3.4E+3	3.4E+3	3.4E+3	3.4E+3	3.4E+3	-	-	-	-	-	-	-	-	-	-	-	-
2	Aromatic C>21-C34	1.4E+3	1.4E+3	1.4E+3	1.4E+3	1.4E+3	1.4E+3	-	-	-	-	-	-	-	-	-	-	-	-
2	F2 (C>10-C16)	8.6E+2	8.6E+2	8.6E+2	8.6E+2	8.6E+2	8.6E+2	-	-	-	-	-	-	-	-	-	-	-	-
2	F3 (C>16-C34)	2.4E+4	2.4E+4	2.4E+4	2.4E+4	2.4E+4	2.4E+4	-	-	-	-	-	-	-	-	-	-	-	-
2	Phenanthrene	2.6E-1	2.6E-1	2.6E-1	2.6E-1	2.6E-1	2.6E-1	-	-	-	-	-	-	-	-	-	-	-	-
2	Pyrene	5.9E-1	5.9E-1	5.9E-1	5.9E-1	5.9E-1	5.9E-1	-	-	-	-	-	-	-	-	-	-	-	-
3	Arsenic	-	-	-	8.0E+0	8.0E+0	8.0E+0	-	-	-	-	-	-	-	-	-	-	-	-
3	Copper	-	-	-	1.0E+1	3.7E+1	1.1E+2	3.0E+1	4.8E+1	6.0E+1	-	-	-	-	-	-	-	-	-
3	Lead	-	-	-	6.0E+1	5.6E+2	1.2E+3	-	-	-	-	-	-	-	-	-	-	-	-
3	Mercury	-	-	-	1.7E+1	3.2E+2	8.8E+2	4.5E+0	4.5E+0	4.5E+0	-	-	-	-	-	-	-	-	-
3	Selenium	-	-	-	2.0E+0	2.0E+0	2.0E+0	1.0E+0	1.0E+0	1.0E+0	-	-	-	-	-	-	-	-	-
3	Zinc	-	-	-	2.0E+1	5.1E+2	1.9E+3	2.0E+1	2.0E+1	2.0E+1	-	-	-	-	-	-	-	-	-
4	Aliphatic C6-C8	-	-	-	2.1E+1	3.7E+2	7.2E+2	-	-	-	2.6E+0	2.6E+0	2.6E+0	-	-	-	-	-	-
4	Aliphatic C>8-C10	-	-	-	1.4E+1	2.4E+2	4.7E+2	-	-	-	2.7E-1	2.7E-1	2.7E-1	-	-	-	-	-	-
4	Aliphatic C>10-C12	-	-	-	3.2E+1	2.5E+2	5.4E+2	-	-	-	1.1E-1	1.1E-1	1.1E-1	-	-	-	-	-	-
4	Aliphatic C>12-C16	-	-	-	4.0E+1	3.1E+2	6.6E+2	-	-	-	6.5E-3	6.5E-3	6.5E-3	-	-	-	-	-	-
4	Aliphatic C>16-C21	-	-	-	8.4E+2	9.4E+3	1.4E+4	-	-	-	4.2E-4	4.2E-4	4.2E-4	-	-	-	-	-	-
4	Aliphatic C>21-C34	-	-	-	3.6E+2	4.0E+3	6.0E+3	-	-	-	-	-	-	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
4	Aliphatic C>34	-	-	-	6.5E+2	1.2E+4	2.2E+4	-	-	-	-	-	-	-	-	-	-	-	-
4	Aromatic C>8-C10	-	-	-	4.0E+0	6.1E+1	1.2E+2	-	-	-	1.4E+0	1.4E+0	1.4E+0	-	-	-	-	-	-
4	Aromatic C>10-C12	-	-	-	8.0E+0	6.3E+1	1.4E+2	-	-	-	2.7E+0	2.7E+0	2.7E+0	-	-	-	-	-	-
4	Aromatic C>12-C16	-	-	-	1.0E+1	7.7E+1	1.7E+2	-	-	-	1.6E+0	1.6E+0	1.6E+0	-	-	-	-	-	-
4	Aromatic C>16-C21	-	-	-	2.1E+2	2.4E+3	3.5E+3	-	-	-	4.2E+0	4.2E+0	4.2E+0	-	-	-	-	-	-
4	Aromatic C>21-C34	-	-	-	9.0E+1	1.0E+3	1.5E+3	-	-	-	2.3E-1	2.3E-1	2.3E-1	-	-	-	-	-	-
4	Aromatic C>34	-	-	-	1.6E+2	2.9E+3	5.4E+3	-	-	-	-	-	-	-	-	-	-	-	-
4	Arsenic	2.6E+1	2.6E+1	2.6E+1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Barium	4.5E+1	4.5E+1	4.5E+1	5.0E+0	5.0E+0	5.0E+0	-	-	-	4.8E-1	4.8E-1	4.8E-1	-	-	-	-	-	-
4	Benzene	-	-	-	1.3E-1	4.8E-1	8.3E-1	-	-	-	1.0E-1	1.0E-1	1.0E-1	-	-	-	-	-	-
4	Benzo[a]anthracene	-	-	-	1.0E+0	1.0E+0	1.0E+0	-	-	-	-	-	-	-	-	-	-	-	-
4	Benzo[a]pyrene	-	-	-	5.0E-1	5.0E-1	5.0E-1	-	-	-	-	-	-	-	-	-	-	-	-
4	Benzo[b,j]fluoranthene	-	-	-	1.4E+0	1.4E+0	1.4E+0	-	-	-	-	-	-	-	-	-	-	-	-
4	Cadmium	4.0E-1	7.5E-1	1.1E+0	5.0E-1	1.1E+0	2.0E+0	-	-	-	-	-	-	-	-	-	-	-	-
4	Chromium (total)	-	-	-	1.2E+2	1.2E+2	1.2E+2	-	-	-	2.0E-3	2.0E-3	2.0E-3	-	-	-	-	-	-
4	Copper	8.4E+1	9.3E+1	1.0E+2	3.8E+1	1.3E+2	2.7E+2	-	-	-	7.0E-3	7.0E-3	7.0E-3	-	-	-	-	-	-
4	Ethylbenzene	-	-	-	2.9E+1	2.9E+1	2.9E+1	-	-	-	1.1E-1	1.1E-1	1.1E-1	-	-	-	-	-	-
4	F1 (C6-C10)	-	-	-	3.9E+1	6.7E+2	1.3E+3	-	-	-	4.3E+0	4.3E+0	4.3E+0	-	-	-	-	-	-
4	F2 (C>10-C16)	-	-	-	9.0E+1	7.0E+2	1.5E+3	-	-	-	4.4E+0	4.4E+0	4.4E+0	-	-	-	-	-	-
4	F3 (C>16-C34)	-	-	-	1.5E+3	1.7E+4	2.5E+4	-	-	-	2.7E-1	2.7E-1	2.7E-1	-	-	-	-	-	-
4	F4 (C>34)	-	-	-	8.1E+2	1.5E+4	2.7E+4	-	-	-	-	-	-	-	-	-	-	-	-
4	Lead	7.3E+1	1.3E+2	1.9E+2	8.7E+1	1.5E+3	2.4E+3	-	-	-	-	-	-	-	-	-	-	-	-
4	Mercury	4.3E-1	4.3E-1	4.3E-1	1.3E-1	3.6E-1	5.8E-1	-	-	-	-	-	-	-	-	-	-	-	-
4	Molybdenum	1.0E+0	1.2E+0	1.4E+0	3.0E+0	3.0E+0	3.0E+0	-	-	-	-	-	-	-	-	-	-	-	-
4	Naphthalene	-	-	-	1.0E-2	7.2E+0	2.0E+1	-	-	-	2.1E-2	2.1E-2	2.1E-2	-	-	-	-	-	-
4	Phenanthrene	-	-	-	1.7E+0	4.1E+0	6.4E+0	-	-	-	-	-	-	-	-	-	-	-	-
4	Pyrene	-	-	-	1.0E+0	1.7E+0	2.3E+0	-	-	-	-	-	-	-	-	-	-	-	-
4	Toluene	-	-	-	6.0E-1	6.0E-1	6.0E-1	-	-	-	4.0E-4	4.0E-4	4.0E-4	-	-	-	-	-	-
4	Xylenes	-	-	-	2.9E+0	1.2E+2	2.3E+2	-	-	-	1.9E+0	1.9E+0	1.9E+0	-	-	-	-	-	-
4	Zinc	1.4E+1	9.7E+1	1.8E+2	2.3E+2	3.1E+2	4.0E+2	-	-	-	2.0E-1	2.0E-1	2.0E-1	-	-	-	-	-	-
5	Acenaphthene	-	-	-	2.3E+1	2.3E+1	2.3E+1	-	-	-	-	-	-	-	-	-	-	-	-
5	Aliphatic C6-C8	9.4E+1	9.4E+1	9.4E+1	3.4E+3	3.4E+3	3.4E+3	2.5E+3	2.5E+3	2.5E+3	-	-	-	-	-	-	-	-	-
5	Aliphatic C>8-C10	6.1E+1	6.1E+1	6.1E+1	2.2E+3	2.2E+3	2.2E+3	1.6E+3	1.6E+3	1.6E+3	-	-	-	-	-	-	-	-	-
5	Aliphatic C>10-C12	6.9E+3	6.9E+3	6.9E+3	1.5E+4	1.5E+4	1.5E+4	4.0E+3	4.0E+3	4.0E+3	-	-	-	-	-	-	-	-	-
5	Aliphatic C>12-C16	8.4E+3	8.4E+3	8.4E+3	1.8E+4	1.8E+4	1.8E+4	4.8E+3	4.8E+3	4.8E+3	-	-	-	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
5	Aliphatic C>16-C21	-	-	-	3.4E+3	3.4E+3	3.4E+3	1.3E+3	1.3E+3	1.3E+3	-	-	-	-	-	-	-	-	-
5	Aliphatic C>21-C34	-	-	-	1.4E+3	1.4E+3	1.4E+3	5.5E+2	5.5E+2	5.5E+2	-	-	-	-	-	-	-	-	-
5	Aromatic C>8-C10	1.5E+1	1.5E+1	1.5E+1	5.4E+2	5.4E+2	5.4E+2	4.1E+2	4.1E+2	4.1E+2	-	-	-	-	-	-	-	-	-
5	Aromatic C>10-C12	8.4E+3	8.4E+3	8.4E+3	1.8E+4	1.8E+4	1.8E+4	4.8E+3	4.8E+3	4.8E+3	-	-	-	-	-	-	-	-	-
5	Aromatic C>12-C16	2.1E+3	2.1E+3	2.1E+3	4.5E+3	4.5E+3	4.5E+3	1.2E+3	1.2E+3	1.2E+3	-	-	-	-	-	-	-	-	-
5	Aromatic C>16-C21	-	-	-	8.4E+2	8.4E+2	8.4E+2	3.2E+2	3.2E+2	3.2E+2	-	-	-	-	-	-	-	-	-
5	Aromatic C>21-C34	-	-	-	3.6E+2	3.6E+2	3.6E+2	1.4E+2	1.4E+2	1.4E+2	-	-	-	-	-	-	-	-	-
5	Benzene	-	-	-	1.2E-2	1.2E-2	1.2E-2	3.2E-2	3.2E-2	3.2E-2	-	-	-	-	-	-	-	-	-
5	Benzo[a]pyrene	-	-	-	2.0E-2	2.0E-2	2.0E-2	-	-	-	-	-	-	-	-	-	-	-	-
5	Benzo[b,j]fluoranthene	-	-	-	2.0E-2	2.0E-2	2.0E-2	-	-	-	-	-	-	-	-	-	-	-	-
5	Chrysene	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	-	-	-	-	-	-	-	-	-	-	-	-
5	Dibenzo[a,h]anthracene	-	-	-	2.0E-2	2.0E-2	2.0E-2	-	-	-	-	-	-	-	-	-	-	-	-
5	Ethylbenzene	6.5E+0	6.5E+0	6.5E+0	2.6E+0	2.6E+0	2.6E+0	3.0E-1	3.0E-1	3.0E-1	-	-	-	-	-	-	-	-	-
5	F1 (C6-C10)	1.7E+2	1.7E+2	1.7E+2	6.1E+3	6.1E+3	6.1E+3	4.5E+3	4.5E+3	4.5E+3	-	-	-	-	-	-	-	-	-
5	F2 (C>10-C16)	1.9E+4	1.9E+4	1.9E+4	4.1E+4	4.1E+4	4.1E+4	1.1E+4	1.1E+4	1.1E+4	-	-	-	-	-	-	-	-	-
5	F3 (C>16-C34)	-	-	-	6.0E+3	6.0E+3	6.0E+3	2.3E+3	2.3E+3	2.3E+3	-	-	-	-	-	-	-	-	-
5	Fluoranthene	-	-	-	3.7E-1	3.7E-1	3.7E-1	-	-	-	-	-	-	-	-	-	-	-	-
5	Fluorene	-	-	-	5.3E+0	5.3E+0	5.3E+0	-	-	-	-	-	-	-	-	-	-	-	-
5	Naphthalene	-	-	-	3.7E+1	3.7E+1	3.7E+1	-	-	-	-	-	-	-	-	-	-	-	-
5	Phenanthrene	-	-	-	5.3E+0	5.3E+0	5.3E+0	-	-	-	-	-	-	-	-	-	-	-	-
5	Pyrene	2.0E-2	2.0E-2	2.0E-2	3.0E-2	3.0E-2	3.0E-2	-	-	-	-	-	-	-	-	-	-	-	-
5	Toluene	2.6E+0	2.6E+0	2.6E+0	1.6E+0	1.6E+0	1.6E+0	3.0E-1	3.0E-1	3.0E-1	-	-	-	-	-	-	-	-	-
5	Xylenes	5.6E+1	5.6E+1	5.6E+1	8.6E+1	8.6E+1	8.6E+1	1.2E+1	1.2E+1	1.2E+1	-	-	-	-	-	-	-	-	-
6	2,4-Dimethylphenol	1.1E+0	1.1E+0	1.1E+0	1.3E-1	1.3E-1	1.3E-1	-	-	-	-	-	-	-	-	-	-	-	-
6	2-Chlorophenol	4.2E-2	4.2E-2	4.2E-2	5.5E-2	5.5E-2	5.5E-2	7.4E-2	7.4E-2	7.4E-2	1.5E-3	1.5E-3	1.5E-3	2.0E-3	2.0E-3	2.0E-3	-	-	-
6	Acenaphthene	3.4E-1	3.4E-1	3.4E-1	1.3E-1	2.1E-1	2.9E-1	-	-	-	1.1E-4	1.1E-4	1.1E-4	6.6E-5	6.6E-5	6.6E-5	9.0E-3	4.2E-2	1.0E-1
6	Acenaphthylene	5.8E-1	5.8E-1	5.8E-1	5.4E-2	5.7E-2	6.1E-2	-	-	-	1.2E-4	1.2E-4	1.2E-4	5.1E-5	6.8E-5	8.5E-5	1.2E-2	7.8E-2	1.7E-1
6	Aliphatic C>10-C12	-	-	-	1.6E+2	1.6E+2	1.7E+2	-	-	-	-	-	-	-	-	-	-	-	-
6	Aliphatic C>12-C16	-	-	-	1.9E+2	2.0E+2	2.1E+2	-	-	-	-	-	-	-	-	-	-	-	-
6	Aliphatic C>16-C21	-	-	-	9.9E+2	1.0E+3	1.0E+3	-	-	-	-	-	-	-	-	-	-	-	-
6	Aliphatic C>21-C34	-	-	-	4.3E+2	4.3E+2	4.3E+2	-	-	-	-	-	-	-	-	-	-	-	-
6	Aliphatic C>34	-	-	-	1.8E+3	2.4E+3	3.0E+3	-	-	-	-	-	-	-	-	-	-	-	-
6	Aluminum	-	-	-	-	-	-	-	-	-	1.8E-2	1.2E-1	2.2E-1	1.2E-1	4.2E+0	1.6E+1	-	-	-
6	Ammonia	-	-	-	-	-	-	-	-	-	2.1E-2	1.7E+0	8.4E+0	5.8E-2	3.8E-1	7.7E-1	-	-	-
6	Anthracene	6.4E-2	5.2E-1	9.7E-1	6.9E-2	1.7E-1	3.4E-1	-	-	-	3.5E-4	3.5E-4	3.5E-4	1.1E-4	1.1E-4	1.1E-4	3.4E-2	8.8E-2	1.6E-1

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
6	Antimony	1.6E+1	8.8E+1	1.8E+2	2.6E+1	1.1E+2	2.9E+2	-	-	-	3.1E-3	3.1E-3	3.1E-3	6.0E-4	2.9E-3	6.7E-3	1.0E+1	2.1E+1	4.0E+1
6	Aromatic C>10-C12	-	-	-	3.9E+1	4.1E+1	4.3E+1	-	-	-	-	-	-	-	-	-	-	-	-
6	Aromatic C>12-C16	-	-	-	4.8E+1	5.1E+1	5.3E+1	-	-	-	-	-	-	-	-	-	-	-	-
6	Aromatic C>16-C21	-	-	-	2.5E+2	2.5E+2	2.5E+2	-	-	-	-	-	-	-	-	-	-	-	-
6	Aromatic C>21-C34	-	-	-	1.1E+2	1.1E+2	1.1E+2	-	-	-	-	-	-	-	-	-	-	-	-
6	Aromatic C>34	-	-	-	4.4E+2	6.0E+2	7.5E+2	-	-	-	-	-	-	-	-	-	-	-	-
6	Arsenic	3.2E+0	3.5E+1	9.0E+1	3.6E+0	2.4E+1	5.3E+1	-	-	-	1.0E-3	3.0E-3	4.9E-3	6.6E-4	3.4E-3	5.3E-3	1.2E+0	1.4E+1	3.3E+1
6	Benzene	5.1E-2	1.5E-1	2.6E-1	7.2E-2	1.0E-1	1.6E-1	-	-	-	1.3E-3	1.3E-3	1.3E-3	2.6E-3	2.6E-3	2.6E-3	4.3E-2	1.0E+0	2.8E+0
6	Benzo[a]anthracene	8.2E-1	8.2E-1	8.2E-1	1.3E-1	2.9E-1	5.8E-1	-	-	-	1.2E-4	8.1E-4	1.5E-3	1.6E-4	1.6E-4	1.6E-4	1.6E-2	4.3E-2	1.0E-1
6	Benzo[a]pyrene	2.2E-1	4.3E-1	5.6E-1	8.2E-2	2.2E-1	4.2E-1	-	-	-	9.8E-5	5.4E-4	9.9E-4	2.4E-5	1.2E-4	2.2E-4	1.0E-2	3.3E-2	7.4E-2
6	Benzo[b,j]fluoranthene	2.4E-1	5.0E-1	7.7E-1	1.4E-1	3.7E-1	7.4E-1	-	-	-	1.3E-4	1.1E-3	2.2E-3	2.6E-4	2.6E-4	2.6E-4	2.2E-2	5.8E-2	1.3E-1
6	Benzo[g,h,i]perylene	2.6E-1	6.0E-1	1.1E+0	7.4E-2	1.7E-1	3.1E-1	-	-	-	7.4E-5	4.4E-4	8.0E-4	3.6E-4	3.6E-4	3.6E-4	1.3E-2	2.8E-2	6.3E-2
6	Benzo[k]fluoranthene	1.9E-1	1.9E-1	1.9E-1	5.0E-2	1.2E-1	1.8E-1	-	-	-	5.5E-4	5.5E-4	5.5E-4	6.5E-5	6.5E-5	6.5E-5	1.0E-2	2.5E-2	3.6E-2
6	Cadmium	2.2E-1	5.5E+0	2.8E+1	1.9E-1	1.7E+0	3.3E+0	-	-	-	2.0E-5	3.5E-4	6.8E-4	1.0E-4	5.0E-4	8.7E-4	1.6E-1	8.2E-1	1.8E+0
6	Chloride	-	-	-	-	-	-	-	-	-	1.8E+0	7.4E+1	2.4E+2	6.5E-1	1.4E+1	2.3E+1	-	-	-
6	Chromium (total)	-	-	-	9.0E+0	9.0E+0	9.0E+0	-	-	-	4.3E-4	2.3E-3	4.1E-3	1.8E-3	1.0E-2	2.3E-2	-	-	-
6	Chrysene	1.0E+0	1.0E+0	1.0E+0	1.8E-1	5.1E-1	8.3E-1	-	-	-	1.2E-4	1.2E-4	1.2E-4	-	-	-	1.7E-2	5.5E-2	1.6E-1
6	Cobalt	-	-	-	-	-	-	-	-	-	7.0E-4	8.2E-3	2.3E-2	2.1E-4	2.5E-3	6.8E-3	-	-	-
6	Copper	3.4E+1	6.4E+2	1.3E+3	2.2E+2	3.4E+2	5.2E+2	-	-	-	8.0E-4	5.9E-3	1.7E-2	2.3E-3	2.6E-2	5.1E-2	3.9E+1	4.3E+1	4.7E+1
6	Cyanide	-	-	-	-	-	-	-	-	-	3.2E-2	5.6E-2	9.4E-2	1.8E-2	2.6E-2	4.0E-2	-	-	-
6	Dibenzo[a,h]anthracene	9.9E-2	1.9E-1	3.6E-1	6.1E-2	8.4E-2	1.1E-1	-	-	-	2.7E-4	2.7E-4	2.7E-4	8.3E-5	8.3E-5	8.3E-5	7.6E-3	1.1E-2	1.7E-2
6	Dichloromethane	-	-	-	-	-	-	-	-	-	1.1E-2	1.4E-2	1.6E-2	6.0E-2	6.0E-2	6.0E-2	-	-	-
6	Dioxin and furans	1.0E-5	7.6E-5	2.2E-4	4.8E-5	4.8E-5	4.8E-5	-	-	-	-	-	-	1.7E-8	3.3E-8	6.0E-8	1.2E-5	2.9E-5	5.6E-5
6	Ethylbenzene	6.1E-2	3.4E-1	6.2E-1	5.4E-2	8.6E-2	1.2E-1	-	-	-	-	-	-	5.9E-4	2.0E-3	3.4E-3	1.5E-1	2.7E-1	4.0E-1
6	F2 (C>10-C16)	-	-	-	4.4E+2	4.6E+2	4.8E+2	-	-	-	-	-	-	-	-	-	-	-	-
6	F3 (C>16-C34)	-	-	-	1.8E+3	1.8E+3	1.8E+3	-	-	-	-	-	-	-	-	-	-	-	-
6	F4 (C>34)	-	-	-	2.2E+3	3.0E+3	3.8E+3	-	-	-	-	-	-	-	-	-	-	-	-
6	Fluoranthene	1.3E-1	7.2E-1	1.7E+0	3.1E-1	6.6E-1	1.1E+0	-	-	-	2.4E-4	1.7E-3	3.2E-3	8.5E-5	2.3E-4	3.7E-4	2.4E-2	1.4E-1	3.3E-1
6	Fluorene	8.7E-1	8.7E-1	8.7E-1	7.8E-2	1.4E-1	1.9E-1	5.3E-2	5.3E-2	5.3E-2	2.0E-4	2.0E-4	2.0E-4	1.0E-4	1.0E-4	1.0E-4	2.2E-2	1.2E-1	2.6E-1
6	Indeno[1,2,3-c,d]pyrene	1.2E-1	2.4E-1	3.7E-1	5.5E-2	1.5E-1	2.4E-1	-	-	-	7.6E-5	3.1E-4	5.4E-4	1.3E-4	1.3E-4	1.3E-4	1.3E-2	2.3E-2	5.7E-2
6	Iron	-	-	-	-	-	-	-	-	-	3.1E+0	1.6E+1	2.9E+1	1.5E-1	1.5E+1	5.1E+1	-	-	-
6	Lead	1.2E+1	7.0E+2	3.3E+3	4.6E+1	2.1E+2	3.5E+2	-	-	-	-	-	-	2.7E-3	2.6E-2	5.6E-2	1.0E+0	9.9E+1	3.2E+2
6	Manganese	-	-	-	-	-	-	-	-	-	2.2E-1	9.9E+0	4.2E+1	1.7E-1	1.2E+0	3.0E+0	9.0E-3	9.0E-3	9.0E-3
6	Cresol-m	1.8E+0	1.8E+0	1.8E+0	4.7E-2	1.9E-1	3.4E-1	-	-	-	-	-	-	-	-	-	-	-	-
6	Mercury	1.5E-2	9.4E-2	2.6E-1	1.2E-2	5.6E-2	1.1E-1	7.0E-2	7.0E-2	7.0E-2	-	-	-	-	-	-	1.6E-2	6.4E-2	1.3E-1

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
6	Molybdenum	3.3E+0	6.0E+0	8.2E+0	-	-	-	-	-	-	6.0E-3	7.7E-3	9.3E-3	1.3E-3	1.3E-3	1.3E-3	-	-	-
6	Naphthalene	5.4E-2	6.9E-1	2.5E+0	2.0E-1	5.2E-1	8.1E-1	-	-	-	3.9E-5	3.7E-4	8.4E-4	1.7E-4	3.3E-4	5.0E-4	2.7E-2	3.8E-1	1.3E+0
6	Cresol-o	2.5E+0	2.5E+0	2.5E+0	6.6E-2	2.3E-1	3.9E-1	-	-	-	-	-	-	6.6E-3	6.6E-3	6.6E-3	-	-	-
6	PCBs (Aroclor 1254)	1.3E-1	1.3E-1	1.3E-1	8.3E-2	8.3E-2	8.3E-2	-	-	-	-	-	-	-	-	-	-	-	-
6	Cresol-p	1.7E+0	1.7E+0	1.7E+0	1.4E-1	2.9E-1	4.5E-1	-	-	-	-	-	-	2.8E-3	2.8E-3	2.8E-3	-	-	-
6	Pentachlorophenol	4.1E-2	4.1E-2	4.1E-2	-	-	-	-	-	-	-	-	-	3.4E-4	3.4E-4	3.4E-4	-	-	-
6	Phenanthrene	6.8E-2	6.9E-1	3.0E+0	6.8E-2	7.2E-1	1.6E+0	1.2E-1	1.2E-1	1.2E-1	1.7E-4	1.4E-3	2.7E-3	5.4E-5	1.8E-4	3.9E-4	2.7E-2	3.1E-1	8.7E-1
6	Phenol	1.1E+1	1.1E+1	1.1E+1	2.1E-1	7.8E-1	1.4E+0	-	-	-	-	-	-	9.4E-3	9.4E-3	9.4E-3	1.3E-1	8.3E-1	1.5E+0
6	Pyrene	2.1E-1	9.5E-1	2.0E+0	2.8E-1	6.5E-1	1.2E+0	-	-	-	2.3E-4	1.6E-3	3.0E-3	1.5E-4	3.1E-4	4.6E-4	1.4E-2	1.3E-1	2.9E-1
6	Silver	-	-	-	1.1E+0	1.1E+0	1.1E+0	-	-	-	-	-	-	6.9E-5	1.1E-4	1.7E-4	-	-	-
6	Styrene	6.1E-2	2.6E-1	4.7E-1	6.6E-2	6.6E-2	6.6E-2	-	-	-	-	-	-	1.6E-3	1.6E-3	1.6E-3	1.9E-1	1.9E-1	1.9E-1
6	Sulphate	-	-	-	-	-	-	-	-	-	1.1E+2	2.8E+2	8.5E+2	5.9E+1	2.2E+2	5.1E+2	-	-	-
6	2,3,4,6-Tetrachlorophenol	-	-	-	-	-	-	-	-	-	2.4E-4	2.4E-4	2.4E-4	6.8E-4	6.8E-4	6.8E-4	-	-	-
6	Tin	5.2E+0	1.2E+3	4.9E+3	1.4E+1	1.8E+1	2.3E+1	3.5E+1	3.5E+1	3.5E+1	-	-	-	-	-	-	8.8E+0	8.8E+0	8.8E+0
6	Toluene	7.7E-2	2.5E-1	4.1E-1	1.3E-1	1.8E+0	3.5E+0	-	-	-	2.2E-3	3.4E-3	5.6E-3	2.5E-3	2.5E-3	2.5E-3	1.1E-1	5.4E-1	1.3E+0
6	Xylenes	3.2E-1	3.2E-1	3.2E-1	2.5E-1	2.5E-1	2.5E-1	-	-	-	2.0E-3	2.5E-3	3.0E-3	-	-	-	3.4E-1	3.4E-1	3.4E-1
6	Zinc	9.0E+0	7.2E+2	2.3E+3	8.4E+1	3.8E+2	6.5E+2	3.8E+1	3.8E+1	3.8E+1	1.0E-3	4.5E-3	8.0E-3	3.1E-2	2.5E-1	9.3E-1	3.1E+1	6.6E+2	2.1E+3
7	Tetrachloroethene	-	-	-	-	-	-	-	-	-	2.9E-1	2.9E-1	2.9E-1	-	-	-	-	-	-
7	Trichloroethene	-	-	-	-	-	-	-	-	-	1.0E+0	1.0E+0	1.0E+0	-	-	-	-	-	-
7	Vinyl Chloride	-	-	-	-	-	-	-	-	-	1.1E-1	1.1E-1	1.1E-1	-	-	-	-	-	-
8	Chloride	2.2E+2	1.9E+3	8.9E+3	2.2E+2	1.9E+3	8.9E+3	-	-	-	-	-	-	-	-	-	-	-	-
8	Conductivity (dS/m)	3.4E+0	4.1E+1	1.3E+2	4.6E+0	9.5E+0	4.9E+1	-	-	-	-	-	-	-	-	-	-	-	-
8	Sodium adsorption ratio	1.4E+1	9.0E+1	2.2E+2	1.0E+0	2.1E+1	5.5E+1	7.0E-1	1.2E+0	1.9E+0	-	-	-	-	-	-	-	-	-
8	Sodium	1.1E+2	1.2E+3	6.0E+3	1.1E+2	1.2E+3	6.0E+3	-	-	-	-	-	-	-	-	-	-	-	-
9	Acenaphthene	-	-	-	-	-	-	3.7E-1	4.1E+1	1.2E+2	3.3E-4	4.1E-4	4.8E-4	-	-	-	-	-	-
9	Acenaphthylene	-	-	-	-	-	-	4.4E-1	4.4E-1	4.4E-1	1.4E-4	1.9E-4	2.3E-4	-	-	-	-	-	-
9	Aliphatic C6-C8	-	-	-	1.5E+0	2.0E+0	2.4E+0	2.3E+0	2.3E+0	2.3E+0	1.2E-2	1.6E-2	1.8E-2	-	-	-	-	-	-
9	Aliphatic C>8-C10	-	-	-	1.0E+0	1.3E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.3E-3	1.7E-3	1.9E-3	-	-	-	-	-	-
9	Aliphatic C>10-C12	-	-	-	7.2E+0	3.7E+1	7.2E+1	8.6E+0	5.9E+1	1.3E+2	1.4E-2	2.3E-2	3.6E-2	-	-	-	-	-	-
9	Aliphatic C>12-C16	-	-	-	8.8E+0	4.5E+1	8.8E+1	1.1E+1	7.2E+1	1.6E+2	8.9E-4	1.4E-3	2.2E-3	-	-	-	-	-	-
9	Aromatic C>16-C21	-	-	-	3.6E+1	1.2E+2	2.0E+2	1.4E+1	1.8E+2	5.6E+2	8.6E-5	8.9E-5	9.5E-5	-	-	-	-	-	-
9	Aliphatic C>21-C34	-	-	-	1.6E+1	5.3E+1	8.4E+1	6.0E+0	7.8E+1	2.4E+2	-	-	-	-	-	-	-	-	-
9	Anthracene	-	-	-	-	-	-	6.1E-1	5.8E+1	1.7E+2	1.2E-4	1.3E-4	1.4E-4	-	-	-	-	-	-
9	Aromatic C>8-C10	-	-	-	2.5E-1	3.2E-1	3.9E-1	3.8E-1	3.8E-1	3.8E-1	6.6E-3	8.9E-3	1.0E-2	-	-	-	-	-	-
9	Aromatic C>10-C12	-	-	-	1.8E+0	9.2E+0	1.8E+1	2.2E+0	1.5E+1	3.2E+1	3.6E-1	5.7E-1	9.1E-1	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
9	Aromatic C>12-C16	-	-	-	2.0E-1	1.1E+1	2.2E+1	2.6E+0	1.8E+1	4.0E+1	2.2E-1	3.5E-1	5.6E-1	-	-	-	-	-	-
9	Aromatic C>16-C21	-	-	-	9.1E+0	3.1E+1	4.9E+1	3.5E+0	4.5E+1	1.4E+2	8.5E-1	8.8E-1	9.5E-1	-	-	-	-	-	-
9	Aromatic C>21-C34	-	-	-	3.9E+0	1.3E+1	2.1E+1	1.5E+0	1.9E+1	6.0E+1	4.6E-2	4.8E-2	5.1E-2	-	-	-	-	-	-
9	Arsenic	-	-	-	2.0E+0	8.0E+0	1.3E+1	3.0E+0	8.3E+0	2.0E+1	4.7E-2	4.7E-2	4.7E-2	-	-	-	9.0E+0	1.4E+1	2.4E+1
9	Benzene	-	-	-	1.3E-1	2.2E-1	3.2E-1	9.7E-2	1.8E-1	2.7E-1	2.0E-3	2.0E-3	2.0E-3	-	-	-	-	-	-
9	Benzo[a]anthracene	-	-	-	-	-	-	9.6E-1	5.5E+1	1.6E+2	9.0E-5	9.0E-5	9.0E-5	-	-	-	-	-	-
9	Benzo[a]pyrene	-	-	-	-	-	-	3.9E-1	3.1E+1	1.2E+2	5.0E-5	5.5E-5	6.0E-5	-	-	-	-	-	-
9	Benzo[b,j]fluoranthene	-	-	-	-	-	-	2.6E-1	2.5E+1	9.5E+1	4.0E-5	5.0E-5	6.0E-5	-	-	-	-	-	-
9	Benzo[g,h,i]perylene	-	-	-	-	-	-	3.8E-1	1.3E+1	4.9E+1	2.0E-5	3.0E-5	4.0E-5	-	-	-	-	-	-
9	Benzo[k]fluoranthene	-	-	-	-	-	-	2.6E-1	2.5E+1	9.5E+1	4.0E-5	5.0E-5	6.0E-5	-	-	-	-	-	-
9	Cadmium	-	-	-	3.0E-1	4.0E-1	5.0E-1	3.0E-1	3.0E-1	3.0E-1	6.0E-4	1.9E-3	3.2E-3	-	-	-	5.6E+0	5.6E+0	5.6E+0
9	Chrysene	-	-	-	-	-	-	1.0E+0	3.9E+1	1.5E+2	9.0E-5	9.5E-5	1.0E-4	-	-	-	-	-	-
9	Copper	-	-	-	3.0E+0	4.8E+1	8.2E+1	1.0E+0	3.4E+1	1.0E+2	6.2E-1	1.1E+0	1.6E+0	-	-	-	2.2E+1	5.6E+1	1.3E+2
9	Dibenzo[a,h]anthracene	-	-	-	-	-	-	1.0E-1	4.4E+0	1.7E+1	2.0E-5	2.0E-5	2.0E-5	-	-	-	-	-	-
9	Ethylbenzene	-	-	-	4.4E-2	9.1E-2	1.4E-1	1.5E-1	1.5E-1	1.5E-1	-	-	-	-	-	-	-	-	-
9	F1 (C6-C10)	-	-	-	2.8E+0	3.6E+0	4.3E+0	4.2E+0	4.2E+0	4.2E+0	2.0E-2	2.7E-2	3.0E-2	-	-	-	-	-	-
9	F2 (C>10-C16)	-	-	-	2.0E+1	1.0E+2	2.0E+2	2.4E+1	1.6E+2	3.6E+2	6.0E-1	9.5E-1	1.5E+0	-	-	-	-	-	-
9	F3 (C>16-C34)	-	-	-	6.5E+1	2.2E+2	3.5E+2	2.5E+1	3.2E+2	1.0E+3	9.0E-1	9.3E-1	1.0E+0	-	-	-	-	-	-
9	Fluoranthene	-	-	-	-	-	-	3.4E-1	9.9E+1	3.8E+2	2.8E-4	3.0E-4	3.2E-4	-	-	-	2.0E-1	2.4E-1	3.0E-1
9	Fluorene	-	-	-	-	-	-	4.4E-1	4.1E+1	1.2E+2	2.9E-4	4.1E-4	5.2E-4	-	-	-	-	-	-
9	Indeno[1,2,3-c,d]pyrene	-	-	-	-	-	-	4.3E-1	2.2E+1	6.4E+1	2.0E-5	3.0E-5	4.0E-5	-	-	-	-	-	-
9	Lead	-	-	-	2.2E+1	1.5E+2	2.6E+2	5.0E+0	2.4E+2	6.6E+2	1.0E+0	1.8E+0	2.5E+0	-	-	-	3.7E+1	1.2E+2	2.1E+2
9	Naphthalene	-	-	-	-	-	-	7.0E-2	3.4E+1	1.3E+2	2.0E-3	2.5E-3	2.9E-3	-	-	-	-	-	-
9	Phenanthrene	-	-	-	-	-	-	7.6E-1	1.5E+2	5.6E+2	5.6E-4	7.0E-4	8.3E-4	-	-	-	3.0E-1	3.0E-1	3.0E-1
9	Pyrene	-	-	-	-	-	-	9.4E-1	7.6E+1	2.9E+2	2.5E-4	2.6E-4	2.6E-4	-	-	-	1.4E-1	1.7E-1	2.0E-1
9	Toluene	-	-	-	6.2E-2	5.0E-1	9.9E-1	6.5E-2	3.1E-1	9.8E-1	1.0E-3	1.0E-3	1.0E-3	-	-	-	-	-	-
9	Xylenes	-	-	-	2.3E-1	6.6E-1	1.1E+0	1.3E-1	4.1E-1	1.0E+0	2.0E-3	2.0E-3	2.0E-3	-	-	-	-	-	-
9	Zinc	-	-	-	4.6E+1	1.2E+2	1.7E+2	1.0E+0	1.3E+2	3.0E+2	1.1E+0	1.3E+0	1.4E+0	-	-	-	2.3E+2	8.7E+2	1.5E+3
10	Acenaphthene	-	-	-	2.0E-2	1.1E-1	3.0E-1	-	-	-	1.0E-5	6.4E-4	6.5E-3	-	-	-	-	-	-
10	Acenaphthylene	-	-	-	1.0E-2	4.0E-2	1.0E-1	-	-	-	1.0E-5	9.9E-5	3.9E-4	-	-	-	-	-	-
10	Aliphatic C6-C8	-	-	-	2.2E+0	3.9E+2	9.9E+2	-	-	-	3.1E-3	1.6E+0	1.1E+1	1.6E-3	1.6E-3	1.6E-3	-	-	-
10	Aliphatic C>8-C10	-	-	-	1.4E+0	2.6E+2	6.5E+2	-	-	-	3.3E-4	1.6E-1	1.2E+0	1.6E-4	1.6E-4	1.6E-4	-	-	-
10	Aliphatic C>10-C12	-	-	-	3.4E+1	3.3E+2	1.1E+3	-	-	-	7.0E-4	3.0E-2	1.8E-1	-	-	-	-	-	-
10	Aliphatic C>12-C16	-	-	-	4.1E+1	4.0E+2	1.3E+3	-	-	-	4.3E-5	1.9E-3	1.1E-2	-	-	-	-	-	-
10	Aliphatic C>16-C21	-	-	-	3.3E+1	2.7E+2	9.0E+2	-	-	-	3.8E-5	7.4E-5	1.1E-4	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
10	Aliphatic C>21-C34	-	-	-	1.4E+1	1.2E+2	3.8E+2	-	-	-	-	-	-	-	-	-	-	-	-
10	Anthracene	-	-	-	1.0E-2	6.0E-2	2.0E-1	-	-	-	2.0E-5	4.1E-4	1.9E-3	-	-	-	-	-	-
10	Aromatic C>8-C10	-	-	-	3.6E-1	6.4E+1	1.6E+2	-	-	-	1.7E-3	8.6E-1	6.2E+0	8.6E-4	8.6E-4	8.6E-4	-	-	-
10	Aromatic C>10-C12	-	-	-	8.5E+0	8.2E+1	2.7E+2	-	-	-	1.7E-2	7.6E-1	4.6E+0	-	-	-	-	-	-
10	Aromatic C>12-C16	-	-	-	1.0E+1	1.0E+2	3.3E+2	-	-	-	1.1E-2	4.7E-1	2.8E+0	-	-	-	-	-	-
10	Aromatic C>16-C21	-	-	-	8.3E+0	6.7E+1	2.2E+2	-	-	-	3.8E-1	7.6E-1	1.1E+0	-	-	-	-	-	-
10	Aromatic C>21-C34	-	-	-	3.4E+0	2.9E+1	9.6E+1	-	-	-	2.0E-2	4.0E-2	6.1E-2	-	-	-	-	-	-
10	Arsenic	-	-	-	1.1E+1	1.1E+1	1.1E+1	-	-	-	7.0E-3	1.2E-2	1.6E-2	-	-	-	-	-	-
10	Benzene	-	-	-	1.0E-2	1.2E+0	2.3E+0	-	-	-	2.0E-4	4.8E-1	3.8E+0	6.0E-4	6.0E-4	6.0E-4	-	-	-
10	Benzo[a]anthracene	-	-	-	1.0E-2	2.2E-2	7.0E-2	-	-	-	1.0E-5	1.8E-4	4.6E-4	-	-	-	-	-	-
10	Benzo[a]pyrene	-	-	-	1.0E-2	1.9E-2	4.0E-2	-	-	-	2.0E-5	1.2E-4	2.9E-4	-	-	-	-	-	-
10	Benzo[b,j]fluoranthene	-	-	-	1.0E-2	2.6E-2	1.0E-1	-	-	-	6.0E-5	1.5E-4	2.4E-4	-	-	-	-	-	-
10	Benzo[g,h,i]perylene	-	-	-	1.0E-2	5.3E-2	2.0E-1	-	-	-	5.0E-5	9.0E-5	1.4E-4	-	-	-	-	-	-
10	Benzo[k]fluoranthene	-	-	-	2.4E-3	3.2E-2	1.0E-1	-	-	-	-	-	-	-	-	-	-	-	-
10	Chrysene	-	-	-	1.0E-2	6.1E-2	3.0E-1	-	-	-	1.0E-5	1.1E-4	3.8E-4	-	-	-	-	-	-
10	Dibenzo[a,h]anthracene	-	-	-	1.0E-2	2.7E-2	4.0E-2	-	-	-	2.0E-5	2.0E-5	2.0E-5	-	-	-	-	-	-
10	Ethylbenzene	-	-	-	2.0E-2	9.0E+0	2.0E+1	-	-	-	2.0E-4	2.4E-1	1.7E+0	2.0E-4	2.0E-4	2.0E-4	-	-	-
10	F1 (C6-C10)	-	-	-	4.0E+0	7.1E+2	1.8E+3	-	-	-	5.2E-3	2.2E+2	2.8E+3	2.6E-3	2.6E-3	2.6E-3	-	-	-
10	F2 (C>10-C16)	-	-	-	9.4E+1	9.1E+2	3.0E+3	-	-	-	2.9E-2	1.3E+0	7.6E+0	-	-	-	-	-	-
10	F3 (C>16-C34)	-	-	-	5.9E+1	4.8E+2	1.6E+3	-	-	-	4.0E-1	8.0E-1	1.2E+0	-	-	-	-	-	-
10	Fluoranthene	-	-	-	1.0E-2	6.4E-2	3.0E-1	-	-	-	2.0E-5	4.4E-4	1.8E-3	-	-	-	-	-	-
10	Fluorene	-	-	-	6.0E-2	2.9E-1	8.0E-1	-	-	-	2.0E-5	6.2E-4	4.2E-3	-	-	-	-	-	-
10	Indeno[1,2,3-c,d]pyrene	-	-	-	1.0E-2	2.0E-2	4.0E-2	-	-	-	1.0E-5	5.3E-5	1.2E-4	-	-	-	-	-	-
10	Lead	-	-	-	2.6E+2	2.6E+2	2.6E+2	-	-	-	1.2E-2	1.2E-2	1.2E-2	-	-	-	-	-	-
10	MTBE	-	-	-	-	-	-	-	-	-	9.0E-4	1.3E-3	1.6E-3	-	-	-	-	-	-
10	Naphthalene	-	-	-	1.0E-2	2.3E+0	5.8E+0	-	-	-	1.0E-5	2.2E-2	2.6E-1	1.0E-5	5.0E-5	9.0E-5	-	-	-
10	Phenanthrene	-	-	-	1.0E-2	3.2E-1	1.8E+0	-	-	-	1.0E-5	9.0E-4	6.4E-3	-	-	-	-	-	-
10	Pyrene	-	-	-	1.0E-2	6.7E-2	4.0E-1	-	-	-	1.0E-5	3.5E-4	1.5E-3	-	-	-	-	-	-
10	Toluene	-	-	-	1.0E-1	1.1E+1	3.2E+1	-	-	-	1.0E-4	1.1E+0	9.9E+0	-	-	-	-	-	-
10	Xylenes	-	-	-	5.0E-2	6.1E+1	2.9E+2	-	-	-	1.0E-4	1.2E+0	9.3E+0	1.0E-3	1.1E-3	1.1E-3	-	-	-
11	Antimony	-	-	-	3.8E+1	3.8E+1	3.8E+1	-	-	-	6.0E-3	6.0E-3	6.0E-3	-	-	-	-	-	-
11	Arsenic	-	-	-	5.0E+0	4.6E+1	8.7E+1	2.4E+2	2.4E+2	2.4E+2	3.3E+1	3.3E+1	3.3E+1	-	-	-	-	-	-
11	Benzene	-	-	-	-	-	-	6.0E-3	6.0E-3	6.0E-3	1.3E-2	1.3E-2	1.3E-2	-	-	-	-	-	-
11	Cadmium	-	-	-	1.7E+1	1.7E+1	1.7E+1	1.5E+1	1.5E+1	1.5E+1	1.2E+0	1.2E+0	1.2E+0	-	-	-	-	-	-
11	Ethylbenzene	-	-	-	-	-	-	2.6E+0	2.6E+0	2.6E+0	1.7E-1	1.7E-1	1.7E-1	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
11	Mercury	-	-	-	4.8E+1	4.8E+1	4.8E+1	-	-	-	-	-	-	-	-	-	-	-	-
11	Nickel	-	-	-	-	-	-	2.1E+2	2.1E+2	2.1E+2	7.9E-1	7.9E-1	7.9E-1	-	-	-	-	-	-
11	Tetrachloromethane	-	-	-	-	-	-	4.0E-1	4.0E-1	4.0E-1	1.2E-1	1.2E-1	1.2E-1	-	-	-	-	-	-
11	Toluene	-	-	-	-	-	-	7.0E-3	7.0E-3	7.0E-3	1.2E-2	1.2E-2	1.2E-2	-	-	-	-	-	-
11	Xylenes	-	-	-	-	-	-	1.5E+1	1.5E+1	1.5E+1	1.0E+0	1.0E+0	1.0E+0	-	-	-	-	-	-
11	Zinc	-	-	-	1.4E+2	1.4E+2	1.4E+2	-	-	-	-	-	-	-	-	-	-	-	-
12	Aliphatic C6-C8	-	-	-	3.3E+2	3.3E+2	3.3E+2	-	-	-	3.2E-1	3.2E-1	3.2E-1	-	-	-	-	-	-
12	Aliphatic C>8-C10	-	-	-	2.2E+2	2.2E+2	2.2E+2	-	-	-	3.0E-2	3.0E-2	3.0E-2	-	-	-	-	-	-
12	Aliphatic C>10-C12	-	-	-	4.3E+1	4.3E+1	4.3E+1	-	-	-	-	-	-	-	-	-	-	-	-
12	Aliphatic C>12-C16	-	-	-	5.2E+1	5.2E+1	5.2E+1	-	-	-	-	-	-	-	-	-	-	-	-
12	Aromatic C>8-C10	-	-	-	5.4E+1	5.4E+1	5.4E+1	-	-	-	1.8E-1	1.8E-1	1.8E-1	-	-	-	-	-	-
12	Aromatic C>10-C12	-	-	-	1.1E+1	1.1E+1	1.1E+1	-	-	-	-	-	-	-	-	-	-	-	-
12	Aromatic C>12-C16	-	-	-	1.3E+1	1.3E+1	1.3E+1	-	-	-	-	-	-	-	-	-	-	-	-
12	Benzene	-	-	-	6.3E+0	6.3E+0	6.3E+0	-	-	-	3.2E-1	3.2E-1	3.2E-1	-	-	-	-	-	-
12	Ethylbenzene	-	-	-	1.4E-1	1.4E-1	1.4E-1	-	-	-	7.0E-3	7.0E-3	7.0E-3	-	-	-	-	-	-
12	F1 (C6-C10)	-	-	-	6.0E+2	6.0E+2	6.0E+2	-	-	-	5.3E-1	5.3E-1	5.3E-1	-	-	-	-	-	-
12	F2 (C>10-C16)	-	-	-	1.2E+2	1.2E+2	1.2E+2	-	-	-	-	-	-	-	-	-	-	-	-
12	Toluene	-	-	-	1.9E+0	1.9E+0	1.9E+0	-	-	-	-	-	-	-	-	-	-	-	-
13	Aliphatic C>10-C12	8.7E+3	8.7E+3	8.7E+3	-	-	-	9.5E+0	9.5E+0	9.5E+0	-	-	-	-	-	-	-	-	-
13	Aliphatic C>12-C16	1.1E+4	1.1E+4	1.1E+4	-	-	-	1.2E+1	1.2E+1	1.2E+1	-	-	-	-	-	-	-	-	-
13	Aliphatic C>16-C21	3.3E+4	3.3E+4	3.3E+4	1.1E+1	1.1E+1	1.1E+1	1.3E+1	1.3E+1	1.3E+1	-	-	-	-	-	-	-	-	-
13	Aliphatic C>21-C34	1.4E+4	1.4E+4	1.4E+4	4.5E+0	4.5E+0	4.5E+0	5.5E+0	5.5E+0	5.5E+0	-	-	-	-	-	-	-	-	-
13	Aromatic C>10-C12	2.2E+3	2.2E+3	2.2E+3	-	-	-	2.4E+0	2.4E+0	2.4E+0	-	-	-	-	-	-	-	-	-
13	Aromatic C>12-C16	2.7E+3	2.7E+3	2.7E+3	-	-	-	2.9E+0	2.9E+0	2.9E+0	-	-	-	-	-	-	-	-	-
13	Aromatic C>16-C21	8.2E+3	8.2E+3	8.2E+3	2.7E+0	2.7E+0	2.7E+0	3.2E+0	3.2E+0	3.2E+0	-	-	-	-	-	-	-	-	-
13	Aromatic C>21-C34	3.5E+3	3.5E+3	3.5E+3	1.1E+0	1.1E+0	1.1E+0	1.4E+0	1.4E+0	1.4E+0	-	-	-	-	-	-	-	-	-
13	Benzene	-	-	-	-	-	-	-	-	-	8.0E-4	8.5E-4	9.0E-4	-	-	-	-	-	-
13	Ethylbenzene	-	-	-	-	-	-	-	-	-	1.3E-3	5.8E-3	1.2E-2	-	-	-	-	-	-
13	F2 (C>10-C16)	2.4E+4	2.4E+4	2.4E+4	-	-	-	2.6E+1	2.6E+1	2.6E+1	-	-	-	-	-	-	-	-	-
13	F3 (C>16-C34)	5.9E+4	5.9E+4	5.9E+4	1.9E+1	1.9E+1	1.9E+1	2.3E+1	2.3E+1	2.3E+1	-	-	-	-	-	-	-	-	-
13	Toluene	-	-	-	-	-	-	-	-	-	6.0E-4	8.0E-4	1.1E-3	-	-	-	-	-	-
13	Xylenes	-	-	-	-	-	-	-	-	-	5.7E-3	2.3E-2	6.3E-2	-	-	-	-	-	-
14	Aliphatic C6-C8	-	-	-	-	-	-	2.6E+1	1.4E+2	2.5E+2	1.3E-1	3.6E-1	5.7E-1	-	-	-	-	-	-
14	Aliphatic C>8-C10	-	-	-	-	-	-	9.4E+0	5.0E+1	9.0E+1	8.6E-3	2.4E-2	3.8E-2	-	-	-	-	-	-
14	Aliphatic C>10-C12	-	-	-	-	-	-	1.2E+1	2.4E+1	3.2E+1	3.0E-3	3.0E-3	3.0E-3	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
14	Aliphatic C>12-C16	-	-	-	-	-	-	1.5E+0	2.7E+1	3.9E+1	1.9E-4	1.9E-4	1.9E-4	-	-	-	-	-	-
14	Aromatic C>8-C10	-	-	-	-	-	-	2.3E+0	1.2E+1	2.3E+1	4.6E-2	1.3E-1	2.0E-1	-	-	-	-	-	-
14	Aromatic C>10-C12	-	-	-	-	-	-	3.0E+0	6.0E+0	8.0E+0	7.5E-2	7.5E-2	7.5E-2	-	-	-	-	-	-
14	Aromatic C>12-C16	-	-	-	-	-	-	3.6E+0	7.3E+0	9.7E+0	4.7E-2	4.7E-2	4.7E-2	-	-	-	-	-	-
14	Benzene	-	-	-	-	-	-	1.7E-1	3.0E+0	3.4E+0	7.0E-4	6.4E-2	1.2E-1	-	-	-	-	-	-
14	Ethylbenzene	-	-	-	-	-	-	5.0E-2	3.1E+0	9.2E+0	1.2E-2	3.8E-2	6.1E-2	-	-	-	-	-	-
14	F1 (C6-C10)	-	-	-	-	-	-	2.6E+1	1.4E+2	2.5E+2	1.3E-1	3.6E-1	5.7E-1	-	-	-	-	-	-
14	F2 (C>10-C16)	-	-	-	-	-	-	3.3E+1	6.6E+1	8.8E+1	1.3E-1	1.3E-1	1.3E-1	-	-	-	-	-	-
14	F3 (C>16-C34)	-	-	-	-	-	-	1.2E+1	1.4E+1	1.7E+1	-	-	-	-	-	-	-	-	-
14	F4 (C>34)	-	-	-	-	-	-	1.7E+1	1.7E+1	1.7E+1	-	-	-	-	-	-	-	-	-
14	Toluene	-	-	-	-	-	-	6.0E-2	3.6E+0	1.1E+1	8.0E-4	1.6E-3	2.0E-3	-	-	-	-	-	-
14	Xylenes	-	-	-	-	-	-	9.0E-2	1.2E+1	4.3E+1	5.5E-2	7.5E-2	8.6E-2	-	-	-	-	-	-
15	Aliphatic C6-C8	-	-	-	-	-	-	-	-	-	7.2E-1	7.2E-1	7.2E-1	-	-	-	-	-	-
15	Aliphatic C>8-C10	-	-	-	-	-	-	-	-	-	4.7E-1	4.7E-1	4.7E-1	-	-	-	-	-	-
15	Aromatic C>8-C10	-	-	-	-	-	-	-	-	-	1.2E-1	1.2E-1	1.2E-1	-	-	-	-	-	-
15	F1 (C6-C10)	-	-	-	-	-	-	-	-	-	1.3E+0	1.3E+0	1.3E+0	-	-	-	-	-	-
15	Toluene	-	-	-	-	-	-	-	-	-	2.0E-3	2.0E-3	2.0E-3	-	-	-	-	-	-
16	2,3,4,6-Tetrachlorophenol	2.0E-2	2.0E-2	2.0E-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Aliphatic C>10-C12	1.0E+1	1.0E+1	1.0E+1	-	-	-	7.2E+1	9.7E+1	1.2E+2	2.4E-3	2.4E-3	2.4E-3	-	-	-	-	-	-
16	Aliphatic C>12-C16	1.3E+1	1.3E+1	1.3E+1	-	-	-	8.8E+1	1.2E+2	1.5E+2	1.5E-4	1.5E-4	1.5E-4	-	-	-	-	-	-
16	Aromatic C>10-C12	2.6E+0	2.6E+0	2.6E+0	-	-	-	1.8E+1	2.4E+1	3.1E+1	6.0E-2	6.0E-2	6.0E-2	-	-	-	-	-	-
16	Aromatic C>12-C16	3.2E+0	3.2E+0	3.2E+0	-	-	-	2.2E+1	3.0E+1	3.7E+1	3.7E-2	3.7E-2	3.7E-2	-	-	-	-	-	-
16	F2 (C>10-C16)	2.9E+1	2.9E+1	2.9E+1	-	-	-	2.0E+2	2.7E+2	3.4E+2	1.0E-1	1.0E-1	1.0E-1	-	-	-	-	-	-
16	Iron	1.0E+4	1.2E+4	1.4E+4	-	-	-	1.4E+4	1.6E+4	1.8E+4	6.5E+0	6.5E+0	6.5E+0	-	-	-	-	-	-
16	Pentachlorophenol	7.0E-3	7.0E-3	7.0E-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Thallium	3.0E+0	3.0E+0	3.0E+0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Toluene	-	-	-	-	-	-	-	-	-	1.6E-3	1.6E-3	1.6E-3	-	-	-	-	-	-
16	Xylenes	-	-	-	-	-	-	-	-	-	1.6E-3	1.6E-3	1.6E-3	-	-	-	-	-	-
16	Zinc	-	-	-	-	-	-	-	-	-	4.4E+2	4.4E+2	4.4E+2	-	-	-	-	-	-
17	Lead	5.6E+1	6.6E+2	1.7E+3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	Zinc	7.2E+2	7.2E+2	7.2E+2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	Aliphatic C>10-C12	-	-	-	-	-	-	1.8E+0	1.8E+0	1.8E+0	-	-	-	-	-	-	-	-	-
18	Aliphatic C>12-C16	-	-	-	-	-	-	2.2E+0	2.2E+0	2.2E+0	-	-	-	-	-	-	-	-	-
18	Aliphatic C>16-C21	-	-	-	-	-	-	1.7E+1	1.7E+1	1.7E+1	-	-	-	-	-	-	-	-	-
18	Aliphatic C>21-C34	-	-	-	-	-	-	7.4E+0	7.4E+0	7.4E+0	-	-	-	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
18	Aliphatic C>34	-	-	-	-	-	-	1.0E+1	1.0E+1	1.0E+1	-	-	-	-	-	-	-	-	-
18	Aromatic C>10-C12	-	-	-	-	-	-	4.5E-1	4.5E-1	4.5E-1	-	-	-	-	-	-	-	-	-
18	Aromatic C>12-C16	-	-	-	-	-	-	5.5E-1	5.5E-1	5.5E-1	-	-	-	-	-	-	-	-	-
18	Aromatic C>16-C21	-	-	-	-	-	-	4.3E+0	4.3E+0	4.3E+0	-	-	-	-	-	-	-	-	-
18	Aromatic C>21-C34	-	-	-	-	-	-	1.9E+0	1.9E+0	1.9E+0	-	-	-	-	-	-	-	-	-
18	Aromatic C>34	-	-	-	-	-	-	2.6E+0	2.6E+0	2.6E+0	-	-	-	-	-	-	-	-	-
18	F2 (C>10-C16)	-	-	-	-	-	-	5.0E+0	5.0E+0	5.0E+0	-	-	-	-	-	-	-	-	-
18	F3 (C>16-C34)	-	-	-	-	-	-	3.1E+1	3.1E+1	3.1E+1	-	-	-	-	-	-	-	-	-
18	F4 (C>34)	-	-	-	-	-	-	1.3E+1	1.3E+1	1.3E+1	-	-	-	-	-	-	-	-	-
19	Anthracene	-	-	-	-	-	-	-	-	-	2.0E-2	2.0E-2	2.0E-2	-	-	-	-	-	-
19	Arsenic	1.3E-1	8.5E-1	3.0E+0	1.0E+0	1.0E+0	1.0E+0	2.0E-1	3.0E-1	4.0E-1	6.0E-4	6.0E-4	6.0E-4	-	-	-	-	-	-
19	Benzo[a]anthracene	6.0E-2	6.0E-2	6.0E-2	1.0E-1	1.0E-1	1.0E-1	-	-	-	-	-	-	-	-	-	-	-	-
19	Benzo[a]pyrene	7.0E-2	7.0E-2	7.0E-2	1.0E-1	1.0E-1	1.0E-1	-	-	-	1.0E-2	1.0E-2	1.0E-2	-	-	-	-	-	-
19	Beryllium	3.1E+0	1.5E+1	3.7E+1	-	-	-	2.0E-1	3.0E-1	4.0E-1	-	-	-	-	-	-	-	-	-
19	Cadmium	2.0E-1	1.1E+0	3.1E+0	4.1E+0	4.1E+0	4.1E+0	-	-	-	1.0E-4	1.5E-4	2.0E-4	-	-	-	-	-	-
19	Copper	2.0E+0	2.0E+1	6.5E+1	4.5E+1	5.9E+1	7.3E+1	-	-	-	1.0E-4	1.5E-4	2.0E-4	-	-	-	-	-	-
19	DDT	8.0E-3	3.5E-2	6.7E-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	Fluoranthene	7.0E-2	7.0E-2	7.0E-2	3.0E-1	3.0E-1	3.0E-1	-	-	-	1.5E-2	1.5E-2	1.5E-2	-	-	-	-	-	-
19	Lead	1.9E+1	1.2E+2	2.8E+2	1.8E+1	2.0E+2	4.0E+2	-	-	-	-	-	-	-	-	-	-	-	-
19	Molybdenum	3.0E+0	1.8E+1	5.6E+1	-	-	-	2.0E-1	3.0E-1	4.0E-1	-	-	-	-	-	-	-	-	-
19	Naphthalene	-	-	-	-	-	-	-	-	-	5.1E-2	5.1E-2	5.1E-2	-	-	-	-	-	-
19	Phenanthrene	6.0E-2	6.0E-2	6.0E-2	2.0E-1	2.0E-1	2.0E-1	-	-	-	6.4E-2	6.4E-2	6.4E-2	-	-	-	-	-	-
19	Pyrene	7.0E-2	7.0E-2	7.0E-2	2.0E-1	2.0E-1	2.0E-1	-	-	-	3.6E-2	3.6E-2	3.6E-2	-	-	-	-	-	-
19	Selenium	9.8E-2	3.1E-1	4.5E-1	4.0E-1	5.4E-1	6.7E-1	2.0E-1	5.5E-1	1.3E+0	-	-	-	-	-	-	-	-	-
19	Silver	-	-	-	-	-	-	-	-	-	2.0E-4	2.0E-4	2.0E-4	-	-	-	-	-	-
19	Sodium	5.4E+1	2.6E+2	6.1E+2	1.8E+2	3.7E+2	5.6E+2	1.4E+2	2.6E+2	3.6E+2	2.0E+2	2.0E+2	2.0E+2	-	-	-	-	-	-
19	Tin	-	-	-	6.3E+0	1.0E+1	1.4E+1	4.0E-1	4.0E-1	4.0E-1	-	-	-	-	-	-	-	-	-
19	Zinc	6.7E+1	5.6E+2	2.0E+3	3.1E+1	1.1E+2	1.5E+2	4.0E-1	9.2E+0	1.8E+1	2.8E-2	2.8E-2	2.8E-2	-	-	-	-	-	-
20	Aliphatic C>10-C12	-	-	-	4.7E+1	4.7E+1	4.7E+1	-	-	-	-	-	-	-	-	-	-	-	-
20	Aliphatic C>12-C16	-	-	-	5.7E+1	5.7E+1	5.7E+1	-	-	-	-	-	-	-	-	-	-	-	-
20	Aliphatic C>16-C21	-	-	-	8.4E+2	8.4E+2	8.4E+2	-	-	-	-	-	-	-	-	-	-	-	-
20	Aliphatic C>21-C34	-	-	-	3.6E+2	3.6E+2	3.6E+2	-	-	-	-	-	-	-	-	-	-	-	-
20	Aliphatic C>34	-	-	-	8.8E+2	8.8E+2	8.8E+2	-	-	-	-	-	-	-	-	-	-	-	-
20	Aromatic C>10-C12	-	-	-	1.2E+1	1.2E+1	1.2E+1	-	-	-	-	-	-	-	-	-	-	-	-
20	Aromatic C>12-C16	-	-	-	1.4E+1	1.4E+1	1.4E+1	-	-	-	-	-	-	-	-	-	-	-	-

Table B-8 Input Contaminant Concentrations from ESA Reports

Site Id.	Contaminant	Media and Concentration																	
		Topsoil (mg/kg)			Surface Soil (mg/kg)			Subsoil (mg/kg)			Groundwater (mg/L)			Surface Water (mg/L)			Sediment (mg/kg)		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
20	Aromatic C>16-C21	-	-	-	2.1E+2	2.1E+2	2.1E+2	-	-	-	-	-	-	-	-	-	-	-	-
20	Aromatic C>21-C34	-	-	-	9.0E+1	9.0E+1	9.0E+1	-	-	-	-	-	-	-	-	-	-	-	-
20	Aromatic C>34	-	-	-	2.2E+2	2.2E+2	2.2E+2	-	-	-	-	-	-	-	-	-	-	-	-
20	F2 (C>10-C16)	-	-	-	1.3E+2	1.3E+2	1.3E+2	-	-	-	-	-	-	-	-	-	-	-	-
20	F3 (C>16-C34)	-	-	-	1.5E+3	1.5E+3	1.5E+3	-	-	-	-	-	-	-	-	-	-	-	-
20	F4 (C>34)	-	-	-	1.1E+3	1.1E+3	1.1E+3	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX C: PQRA RESULTS AND NCSCS SCORES

C.1. Cumulative Hazard Indices

Table C-1 Cumulative Hazard Indices

Site Identifier	Known Cumulative Hazard Indices, $knCI_k$								
	Human	Plants & Invert.	Soil Microbes	Cow	Meadow Vole	Masked Shrew	American Kestrel	Aquatic Life	Average Eco.
1	1.8E+02	2.9E+01	3.8E+00	0	6.3E+00	8.6E+01	3.8E+00	1.3E+03	4.3E+00
2	1.7E+01	1.7E+01	0	0	0	0	0	0	5.6E-04
3	7.3E+01	8.8E+01	5.5E+01	0	8.9E+00	4.9E+01	2.8E+00	0	6.7E-01
4	1.3E+00	4.2E+01	7.8E+00	0	0	0	0	0	3.2E-03
5	3.7E+01	1.8E+02	0	0	0	0	0	0	7.8E-04
6	1.8E+03	1.0E+03	1.5E+01	1.0E+01	4.4E+01	1.0E+03	2.6E+01	2.9E+02	9.0E+01
7	7.4E+01	0	0	0	0	0	0	0	0
8	0	1.1E+02	0	0	0	0	0	0	7.3E-04
9	2.6E+01	2.3E+00	1.4E+00	0	0	0	0	3.2E+01	1.0E-02
10	5.0E-01	1.9E+01	3.6E-01	0	0	0	0	1.5E-01	5.2E-03
11	5.3E+00	6.4E+00	3.4E+00	0	0	0	0	0	2.2E-03
12	4.1E-02	2.4E+00	0	0	0	0	0	0	4.2E-04
13	1.8E+02	3.6E+02	0	1.8E+00	4.6E+00	5.9E+00	0	0	7.8E-02
14	1.5E+02	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0
16	6.7E+00	2.1E+00	0	1.4E-01	3.4E-01	4.3E-01	0	0	1.2E-02
17	9.1E-02	4.8E+00	4.3E+00	0	0	0	0	0	2.1E-03
18	3.4E+00	0	0	0	0	0	0	0	0
19	7.5E+01	1.6E+01	1.0E+01	1.2E+00	8.3E+00	3.7E+01	2.7E+00	0	1.5E+00
20	0	6.3E+00	0	0	1.8E-01	2.3E-01	0	0	4.3E-03

Site Identifier	Potential Cumulative Hazard Indices, $poCI_k$								
	Human	Plants & Invert.	Soil Microbes	Cow	Meadow Vole	Masked Shrew	American Kestrel	Aquatic Life	Average Eco.
1	3.8E+03	3.0E+01	3.8E+00	0	6.4E+00	8.6E+01	3.8E+00	1.4E+04	6.2E+00
2	2.4E+01	1.7E+01	0	0	9.2E-04	1.2E-03	0	0	1.1E-03
3	2.1E+03	8.8E+01	5.5E+01	0	8.9E+00	4.9E+01	2.8E+00	2.8E+03	7.8E+00
4	3.6E+03	4.3E+01	7.8E+00	0	0	0	0	9.3E+01	2.3E-02
5	3.7E+01	2.3E+02	0	0	0	0	0	0	8.1E-04
6	1.6E+04	1.0E+03	1.5E+01	3.2E+01	5.1E+01	1.0E+03	2.6E+01	2.9E+02	1.1E+02
7	1.3E+02	0	0	0	0	0	0	0	0
8	4.6E+00	1.3E+02	0	0	0	0	0	9.3E-01	2.8E-03
9	3.7E+02	2.3E+00	1.4E+00	0	0	0	0	3.2E+01	1.0E-02
10	2.9E+02	1.9E+01	3.6E-01	0	0	0	0	4.5E+02	1.6E-02
11	1.5E+05	1.3E+01	3.4E+00	9.7E+00	7.9E+00	1.6E+02	4.2E+00	5.6E+02	2.0E+01
12	6.0E+02	2.4E+00	0	0	0	0	0	0	4.2E-04
13	3.8E+02	3.6E+02	0	2.0E+00	4.6E+00	5.9E+00	0	0	7.9E-02
14	4.3E+03	0	0	2.0E+01	0	0	0	0	5.7E-04
15	1.8E+01	0	0	5.0E-03	0	0	0	0	1.7E-04
16	3.4E+03	5.9E+02	0	3.9E+01	3.4E-01	4.3E-01	0	0	6.2E-02
17	9.1E-02	4.8E+00	4.3E+00	0	0	0	0	0	2.1E-03
18	3.6E+00	0	0	0	0	0	0	0	0
19	5.1E+02	6.2E+01	7.2E+00	1.9E+00	7.9E+00	3.6E+01	2.7E+00	1.0E+02	1.3E+01
20	0	6.3E+00	0	0	1.8E-01	2.3E-01	0	0	4.3E-03

C.2. NCSCS Score Summary

Table C-2 NCSCS Score Summary

Factor Number	Evaluation Factor[1]	Max.	Site Identifier and NCSCS Factor Scores																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	I. Contaminant Characteristics	**33**	**30**	**13**	**18**	**21**	**17**	**27**	**17**	**10**	**20**	**21**	**27**	**17**	**15**	**21**	**13**	**15**	**12**	**8**	**21**	**7**
	1. Residency media	8	8	4	6	6	2	8	4	4	4	6	8	2	4	4	2	4	2	2	6	2
1	A. Soil	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2
2	B. Groundwater	2	2	2	2	2	0	2	2	2	0	0	2	0	2	2	2	2	0	0	2	0
3	C. Surface water	2	2	0	0	0	0	2	0	0	0	2	2	0	0	0	0	0	0	0	2	0
4	D. Sediment	2	2	0	2	2	0	2	0	0	2	2	2	0	0	0	0	0	0	0	0	0
5	2. Chemical Hazard	8	8	4	8	8	8	8	8	2	8	8	8	8	4	8	8	4	8	4	8	2
6	3. Contaminant Exceedance	8	6	4	6	6	6	6	4	4	6	6	6	6	6	6	4	6	2	2	6	2
7	4. Contaminant quantity	9	9	2	2	2	2	6	2	2	2	2	9	2	2	6	2	2	2	2	2	2
	5. Modifying Factors	7	5	2	0	3	2	5	2	0	4	4	2	2	2	2	0	2	0	0	4	0
8	A. Persistent chemical?	2	2	0	0	0	0	2	0	0	2	2	0	0	0	0	0	0	0	0	2	0
9	B. Utility damaging?	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
10	C. Number of contaminant classes	3	3	2	0	3	2	3	0	0	2	2	2	2	2	2	0	2	0	0	2	0
	II. Migration Potential	**33**	**26**	**17**	**15**	**20**	**12**	**29**	**11**	**11**	**9**	**25**	**24**	**13**	**15**	**10**	**5**	**15**	**6**	**6**	**15**	**6**
	1. Groundwater movement	12	9	9	9	9	0	12	9	9	0	12	9	0	9	9	0	9	0	0	9	0
11	A. Known	12	9	9	9	9	0	12	9	9	0	12	9	0	9	9	0	9	0	0	9	0
	B. Potential	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	a. Relative mobility	4	4	2	2	4	-	4	4	4	-	4	4	-	2	4	-	2	-	-	2	-
13	b. Presence of sub-surface containment	3	3	3	3	3	-	3	3	3	-	3	3	-	3	3	-	3	-	-	3	-
14	c. Confining layer thickness	1	0.5	0.5	0.5	0.5	-	0.5	0.5	0.5	-	0.5	0.5	-	0.5	0.5	-	0.5	-	-	0.5	-
15	d. Confining layer hydraulic conductivity	1	0.5	0.5	0.5	0.5	-	0.5	0.5	0.5	-	0.5	0.5	-	0.5	0.5	-	0.5	-	-	0.5	-
16	e. Precipitation infiltration rate	1	0.9	1.0	0.6	1.0	-	0.4	0.5	0.8	-	0.7	0.5	-	0.3	0.1	-	0.1	-	-	0.2	-
17	f. Aquifer hydraulic conductivity	2	1	1	1	1	-	0	1	1	-	1	1	-	1	0	-	0	-	-	1	-
	2. Surface water movement	12	12	0	0	0	0	12	0	0	0	12	8	0	0	0	0	0	0	0	8	0
18	A. Known	12	12	0	0	0	0	12	0	0	0	12	8	0	0	0	0	0	0	0	8	0
	B. Potential	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	a. Presence of containment	5	5	-	-	-	-	5	-	-	-	5	3	-	-	-	-	-	-	-	5	-
20	b. Distance to surface water	3	3.0	-	-	-	-	3.0	-	-	-	3.0	0.5	-	-	-	-	-	-	-	2.0	-
21	c. Topography	2	1.5	-	-	-	-	0.5	-	-	-	0.0	0.0	-	-	-	-	-	-	-	1.5	-
22	d. Runoff potential	1	0.5	-	-	-	-	0.7	-	-	-	0.4	0.3	-	-	-	-	-	-	-	0.3	-
23	e. Flood potential	1	0.0	-	-	-	-	0.2	-	-	-	0.0	0.0	-	-	-	-	-	-	-	0.0	-

Table C-2 NCSCS Score Summary

Factor Number	Evaluation Factor[1]	Max.	Site Identifier and NCSCS Factor Scores																			
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	3. Surface soil impacts	12	12	12	12	12	12	12	0	12	0	12	12	12	12	0	0	12	12	0	12	12
24	A. Known	12	12	12	12	12	12	12	0	12	0	12	12	12	12	0	0	12	12	0	12	12
	B. Potential	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	a. Soils covered?	6	6	6	4	6	4	6	-	6	-	4	4	0	6	-	-	4	6	-	4	2
26	b. Snow covered ≥ 1 cm?	6	0	0	0	0	0	0	-	3	-	0	0	0	0	-	-	0	0	-	3	0
	4. Vapours	12	9	9	0	9	9	9	9	0	9	9	9	9	9	9	9	9	0	9	0	0
27	A. Known	12	9	9	0	9	9	9	9	0	9	9	9	9	9	9	9	9	0	9	0	0
	B. Potential	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	a. Volatility	4	4	4	-	4	4	4	4	-	4	4	4	4	4	4	4	4	-	4	-	-
29	b. Soil grain size	4	2	4	-	4	2	2	4	-	4	4	4	4	4	2	2	2	-	4	-	-
30	c. Depth to source	2	2	2	-	2	2	2	2	-	2	2	2	2	2	2	2	2	-	2	-	-
31	d. Preferential pathways	2	0	2	-	0	2	0	2	-	0	0	0	2	0	1	0	0	-	1	-	-
	5. Sediment movement	12	9	0	8	8	0	12	0	0	8	4	9	0	0	0	0	0	0	0	0	0
32	A. Known	12	9	0	-	-	0	12	0	0	-	-	9	0	0	0	0	0	0	0	0	0
	B. Potential	-	-	-	8	8	-	-	-	-	8	4	-	-	-	-	-	-	-	-	-	-
33	a. Capped sediments?	4	4	-	4	4	-	4	-	-	4	4	4	-	-	-	-	-	-	-	-	-
34	b. Sediments in shallow lake/marine water?	4	0	-	4	4	-	0	-	-	4	0	0	-	-	-	-	-	-	-	-	-
35	c. Sediments in river scour area?	4	4	-	0	0	-	4	-	-	0	0	4	-	-	-	-	-	-	-	-	-
36	6. Modifying factors (utility conduits)	4	0	2	0	0	2	0	4	0	0	0	0	4	0	2	0	0	0	2	0	0
	III. Exposure	**34**	**25**	**21**	**16**	**16**	**16**	**25**	**7**	**21**	**16**	**16**	**16**	**16**	**16**	**16**	**7**	**16**	**9**	**7**	**16**	**9**
	Total Human Score	**22**	**16**	**16**	**10**	**10**	**10**	**16**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**0**	**10**	**10**	**0**
	1. Human Receptors	22	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	10	10	0
37	A. Known	22	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	10	10	0
	B. Potential	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	a. Land use	3.0	2.0	1.0	2.0	0.5	1.0	3.0	1.0	3.0	1.0	0.5	3.0	0.5	3.0	3.0	3.0	3.0	-	2.0	3.0	-
39	b. Site accessibility	2	2	2	1	1	2	2	1	2	1	1	2	0	2	1	1	1	-	1	2	-
	c. Contaminant intake potential	17	10	6	7	3	9	13	6	3	3	3	10	5	10	6	6	7	0	6	4	0
40	i. Direct contact	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	-
	ii. Inhalation	6	3	3	0	3	3	6	3	0	3	3	3	3	3	3	3	3	0	3	0	0
41	- Vapour	3	3	3	0	3	3	3	3	0	3	3	3	3	3	3	3	3	-	3	0	-
42	- Dust	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	-	0	0	-

Table C-2 NCSCS Score Summary

Factor Number	Evaluation Factor[1]	Max.	Site Identifier and NCSCS Factor Scores																			
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	iii. Ingestion	8	7	3	7	0	6	7	3	3	0	0	7	2	7	3	3	4	0	3	4	0
43	- Drinking water supply	3	3	3	3	0	3	3	3	3	0	0	3	2	3	3	3	3	0	3	3	0
44	- Alternate water supply?	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	-
45	- Human ingestion of soil possible?	3	3	0	3	0	3	3	0	0	0	0	3	0	3	0	0	0	-	0	0	-
46	- Contaminated food consumption?	1	1	0	1	0	0	1	0	0	0	0	1	0	1	0	0	1	-	0	1	-
47	2. Human Receptors Modifying Factors	6	6	6	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Ecological Score	**18**	**18**	**12**	**12**	**12**	**12**	**18**	**0**	**18**	**12**	**12**	**12**	**12**	**12**	**12**	**0**	**12**	**12**	**0**	**12**	**12**
	3. Ecological Receptors	18	18	12	12	12	12	18	0	18	12	12	12	12	12	12	0	12	12	0	12	12
48	A. Known exposure	18	18	12	12	12	12	18	0	18	12	12	12	12	12	12	0	12	12	0	12	12
	B. Potential exposure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	a. Terrestrial receptors	10	5	2	4	2	2	7	0	4	2	3	6	2	5	4	0	5	2	0	4	4
49	i. Land use	3.0	2.0	1.0	2.0	0.5	1.0	3.0	-	3.0	1.0	0.5	3.0	0.5	3.0	3.0	-	3.0	0.5	-	3.0	3.0
50	ii. Plant and invertebrate uptake	1	1	1	1	1	1	1	-	1	0	1	1	1	1	0	-	1	1	-	1	1
	iii. Ingestion	6	2	0	1	0	0	3	0	0	1	1	2	0	1	1	0	1	0	0	0	0
51	- Water?	1	0	0	0	0	0	1	-	0	0	0	1	0	0	1	-	1	0	-	0	0
52	- Soil?	1	1	0	1	0	0	1	-	0	0	0	1	0	1	0	-	0	0	-	0	0
53	- Bioaccumulating chemical?	1	1	0	0	0	0	1	-	0	1	1	0	0	0	0	-	0	0	-	0	0
54	- Sensitive terrestrial eco receptor	3	0	0	0	0	0	0	-	0	0	0	0	0	0	0	-	0	0	-	0	0
	b. Aquatic receptors	8	6	2	5	5	2	6	0	3	6	6	4	2	4	4	0	2	4	0	6	4
55	i. Aquatic life classification	3	1	0	1	1	0	1	-	1	1	1	1	1	1	1	-	1	1	-	1	1
	ii. Uptake potential	5	5	2	4	4	2	5	0	2	5	5	3	1	3	3	0	1	3	0	5	3
56	- Does groundwater daylight?	1	1	0	1	1	0	0.5	-	0	0.5	1	1	0	0	0	-	0	0	-	1	0
57	- Distance to surface water resource	3	3	2	3	3	2	3	-	2	3	3	2	1	3	3	-	1	3	-	3	3
58	- Bioaccumulate in fish consumers?	1	1	0	0	0	0	1	-	0	1	1	0	0	0	0	0	0	0	-	1	0
	4. Ecological Receptors Modifying Factors	10	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	A. Known species at risk	2	0	0	0	0	0	0	-	0	0	0	0	0	0	0	-	0	0	-	0	0
	B. Potential aesthetic impacts	8	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	a. to receiving water bodies	2	2	0	0	0	0	2	-	0	0	0	0	0	0	0	-	0	0	-	0	0
61	b. olfactory impacts	2	0	0	0	0	0	2	-	0	0	0	0	0	0	0	-	0	0	-	0	0
62	c. increased plant growth	2	0	0	0	0	0	0	-	0	0	0	0	0	0	0	-	0	0	-	0	0
63	d. fish or meat smelly etc	2	0	0	0	0	0	0	-	0	0	0	0	0	0	0	-	0	0	-	0	0

Table C-2 NCSCS Score Summary

Factor Number	Evaluation Factor[1]	Max.	Site Identifier and NCSCS Factor Scores																		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	5. Other Potential Contaminant Receptors	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	A. Eroded permafrost structural damage	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	B. Permafrost soil transport to aquatic	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total NCSCS Score for Site[2]		**100**	**81**	**50**	**49**	**56**	**45**	**82**	**35**	**41**	**45**	**63**	**68**	**46**	**47**	**48**	**25**	**47**	**27**	**21**	**53**	**22**

Notes:

[1] Factor explanations and allowable scores are located in Canadian Council of Ministers of the Environment. 2008. *National Classification System for Contaminated Sites:*

[2] Result rounded to the nearest integer