

UNIVERSITY OF CALGARY

A Decision Support System  
for Risk Management of Contaminated Sites

by

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## **ABSTRACT**

Large municipalities are entrusted with management of thousands of properties while working under restricted budgets. With an increasing number of contaminated sites being identified each year, municipal site managers are forced to prioritize. This is extremely difficult given the variations in parameters that define the characteristics of a site making each site different from every other. A scientifically defensible, multi-level multi-criteria decision support system was developed and computerized to assist with prioritizing contaminated sites and selecting the appropriate remedial action(s) / management option. The model utilizes a rule-based system to first identify those sites that may pose a risk and advance them to Phase I and potentially Phase II Environmental Site Assessments (ESA). The final level of the Decision Support System focuses on ranking and classification of those Phase II ESA sites by evaluating and combining potential impacts of contamination on human and ecological health, with political impact, legislative compliance, and cost.

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## **DEDICATION**

To the strong women who have influenced and shaped my life:

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## **EPIGRAPH**

Virtually every aspect of life involves risk. How we deal with risk depends largely on how well we understand it.

National Research Council, Science and Decisions: Advancing Risk Assessment

## CHAPTER ONE: INTRODUCTION

### 1.1 GENERAL

Management of contaminated sites is a major responsibility of any large municipality. With an increasing number of sites being identified each year, and resources being limited, municipal environmental engineers are forced to prioritize. Variations in parameters that define the characteristics of a site, such as topography, geology, hydrogeology, contaminant type and concentrations, location, and proximity to sensitive areas make each site different from every other. These differences lead to each site posing varying risks to human and ecological health and it is through the evaluation of these risks that decision makers can set priorities for action.

Decision makers seldom have the time and resources to perform detailed analyses; they rely on the expertise of others. The actions taken are based partly on the results of the analysis and partly on the intuition of the decision maker. The efficacy of intuitive decisions is difficult to assess because intuition depends on experience (i.e. personal knowledge gained through formal training and/or exposure to similar situations) to recognize key patterns. The decision maker's experience coupled with motivational factors such as budgetary constraints and political considerations influence the actions selected. Decision makers try to project the future, and in so doing personal biases are inevitably introduced; biases on interpretation of information, recall of previous events and information, and personal interests (Klein 1998; Virine and Trumper 2000). Experience will differ from one decision maker to the other, and the results will reflect the objectives and priorities of the "*individual of the day*".

Decision making support systems (DMSS) are information systems that are designed to work with and support the decision maker (Mora et al. 2003). They standardize the process by incorporating the pertinent data, knowledge, and expertise into a model that can capture, store, select, and analyze the information so as to deliver the desired result



(report, decision advice, etc.) to the decision maker, thereby reducing the influence of individual biases (Forgionne 2003). For the results of a DMSS to be accepted as a foundation for action(s), the methodology developed must be scientifically defensible, systematic, sensitive to variations in data, politically acceptable, simple and inexpensive to implement (Corvalan et al. 2000b).

As Environmental and Human Health Risk Assessments have become increasingly information-intensive and complex, the development and application of decision making strategies has evolved as a crucial component of the assessment process. In order for the decision maker to identify, assess and mitigate potential impacts of contaminants at a site they need an understanding of the relationship between the organisms and the environment which supports them. Environmental factors can directly or indirectly, negatively or positively affect an organism's survival. Thus, clear and measurable indicators are necessary to ensure that appropriate actions are taken. Indicators are measurements that reflect the significance of a concept; a way of expressing the link between scientific knowledge and a specific outcome. They are generally developed by scientists and policy makers to convert raw data into something meaningful that decision makers can use (Corvalan et al. 2000a; Spiegel and Yassi 1997). For example, while environmental health indicators such as cancer, respiratory disease, allergies, etc., exemplify the link between environmental conditions and human health the presence of contaminants in the environment does not necessarily directly translate into health effects. Thus, the indicator that is most widely used is the degree of exposure of humans to potential health risks (Corvalan et al. 2000a). The United States Environmental Protection Agency (USEPA) and Health Canada have provided basic formulae that can be used to *guide* assessors in determining the potential health risks associated with exposure to chemicals in the environment, both natural and anthropogenic (Health Canada 2004a; USEPA 1989). Interpretation and application of the formulae are based on the information available and at the discretion of the assessor.

Analysis of available data on human health and the environment can be overwhelming to the decision maker yet the process is a valuable tool that provides estimates of the impact

of contamination. Standards and guidelines based on epidemiological and toxicological studies have been developed providing the maximum acceptable levels that would be protective of organisms. Comparisons with guideline values are made to establish a measure of the association between contaminant levels, degree of compliance with current policies and potential risk (Corvalan et al. 2000b). The precision is based on the quality of the available data which is often highly variable, incomplete, linguistic in nature, vague and uncertain.

Several approaches are available that vary from simple scoring systems, such as the National Classification System for Contaminated Sites (CCME 2008) and the Washington Ranking Method (Robb 1990), to more integrated analytic decision systems such as comparative risk assessment (CRA) (Belzer et al. 2004; Cura et al. 2004; Embleton et al. 1996) or expansive multi-criteria decision making (MCDM) models (Figueria et al. 2005b; Triantaphyllou and Mann 1995).

Contaminated site assessment and management is a multi-dimensional problem that requires the balancing of scientific findings with various stakeholder inputs and, as such, the DSS selected should provide a systematic and transparent framework that can be used to integrate the all the applicable available information and present it in a manner that captures its relevance (Kiker et al. 2008; Linkov et al. 2006; Pomerol and Adam 2003). Multi-criteria/multi-objective decision making (MCDM) encompasses a number of methods and models to help and guide decision makers through the process. It provides a valuable tool for dealing with multiple objectives, multiple risks and uncertainties, and multiple stakeholders to obtain estimates of potential impact that can be used to rank sites and set priorities for action (Nobre et al. 1999; Virine and Trumper 2000).

## **1.2 RESEARCH OBJECTIVES**

The primary goal of this research is to develop a user-friendly, transparent, standardized, scientifically defensible multi-objective decision making methodology that can be used by Municipal Environmental Managers to effectively assess the potential risk associated with a contaminated site and set priorities for action. This will be accomplished through

the examination of existing human health and ecological risk assessment paradigms and the associated regulatory guidelines, investigation of currently available contaminated site ranking systems, and the investigation of multiple-criteria decision making methodologies. While the current target is the Municipality of Calgary Alberta, the methodology can be extended to other municipalities.

### **1.3 THESIS ORGANIZATION**

The thesis consists of six (6) chapters:

Chapter 1 describes the need for a standardized decision system, as well as the goal and objective of the thesis.

Chapter 2 provides a review of contaminated site management, decision making with reference to the human health and ecological risk assessment, and multi-criteria decision making methodologies used in risk assessment.

Chapter 3 describes the basic framework for the multi-level Multi-Criteria Decision Making (MCDM) model developed to aid Municipal Environmental Managers in their decision-making process.

Chapter 4 provides a detailed description Classification and Ranking of Sites for Phase I Environmental Site Assessments methodology and the results from its application.

Chapter 5 describes the methodology behind the Further Classification for Site Management component of the Decision Support System and illustrates the method application.

Chapter 6 describes the development and application of an alternative methodology for ranking of contaminated sites, Fuzzy PROMETHEE.

Chapter 7 provides the main conclusions, model limitations and recommendations for future research.

## CHAPTER TWO: LITERATURE REVIEW

### 2.1 CONTAMINATED SITE MANAGEMENT

Contaminated land is one of the principal environmental risks associated with property. Some risks are obvious, direct, immediate and occur in defined areas, whereas others are hidden, indirect, delayed and have the propensity for widespread consequences. Regardless of the nature of the environmental risk, virtually all are anthropogenic in nature and societal expectations are driving organizations to become more transparent in terms of disclosing appropriate risk controls ((Bohm et al. 2001; Covello and Mumpower 1994; Pritchard 2000; Slovic 1994). Whether the organization is small or large, publicly or privately owned/operated, it is society that provides the organization a “*social licence to operate*”. When the organization is a municipality that is charged with managing properties essentially through the financial support of its citizens, there is a moral obligation to provide accountability and transparency in its actions(Wilson et al. 2002) . This moral obligation is fulfilled under the guise of “due diligence”.

With the increasing interest in environmental protection, risk assessment has moved beyond the scientific/academic realm and is forming the basis of government policy. The release of guidelines and standards provide organizations with a scientifically defensible foundation for developing risk management programs and implementing environmental policies (Pritchard 2000; Shatkin et al. 2004). Management of contaminated sites requires decision makers to weigh existing risks against the potential effects that can result from different actions. The adoption and implementation of policies to mitigate the risk of environmental contamination is influenced by the perceptions and interpretations people have and make about risk (Mileti 1994) and thus the risk management programs developed will most likely extend beyond the requirements of legislation. This in turn

will pressure regulators into providing further guidance and standards in environmental areas (Covello and Mumpower 1994; Pritchard 2000; Slovic 1994).

The advantages of implementing risk management programs extend beyond improved public perception. Other benefits include reduced capital costs, more accurate financial projection and reporting, better informed strategic decisions, increased operating efficiency, and regulatory compliance (AIRMIC et al. 2010). Risk management is a process that is based on a set of principles and is applied as an operation tool. In the past, risk management decisions were based primarily on common sense, ordinary knowledge, trial and error, or non-scientific knowledge and beliefs. Today, there is an increased reliance on highly technical quantitative risk analyses adding to the existing challenges faced by Municipal Environmental Site Managers charged with the management of large number of municipal owned and/or operated properties (AIRMIC et al. 2010; Covello and Mumpower 1994; Pritchard 2000). Risk analysis/assessment has proven to be a valuable tool for environmental decision making worldwide (Bell and Wilson 2001).

The role of Site Managers is continually expanding to include the need for satisfying regulatory obligations, protecting human health and ecology, and managing public perception all while working under increasing budgetary constraints. Incorporating risk management as an integral part of the organizations' process creates value in that it becomes part of the decision making process. However, the cost of obtaining the information required to make informed decisions can be expensive as there is a reliance on external, unbiased specialists. A tiered approach to the collection of information can reduce investigative costs by allocating resources in a manner that balances the detail with need (Pritchard 2000).

## **2.2 PHASED ENVIRONMENTAL SITE ASSESSMENTS**

Increasing societal awareness of environmental conditions has resulted in the increased use of Environmental Site Assessments (ESA's) prior to the completion of property transactions. ESA's have become a means of gathering information for identifying and assigning liability to the appropriate property owners/operators. ESA's are used to

determine if the potential for contamination exists at a site, what the nature of the contaminant(s) may be, their quantity and distribution throughout the site, the possibility of migration beyond the boundaries, the risk associated with exposure to the contaminants and the means of mitigating the risks. The risk investigation is typically based on a source-pathway-receptor approach. As all properties are not identical, a phased approach is used for the assessment process with each successive phase increasing in complexity and detail of analysis (AENV 2001a).

### ***2.2.1 Phase I Environmental Site Assessment***

Phase I ESA's are conducted through a systematic process to determine whether a given property/site has been, or is being, subjected to some form of contamination. It is a non-intrusive, data gathering investigation that is documentary in nature. The data collected is comprehensive and includes the analysis of site maps and records for existing and historical activities and events at the site, historical land use, waste disposal records, discharge consents, etc. Current and historical land uses can provide valuable information indicating the existence or likelihood of surface and/or subsurface contamination at the site. Following the document search, a Phase I ESA will typically include a site visit where a visual inspection of the property is made so as to identify any areas or regions of concern such as stressed or lack of vegetation, oil spills, evidence of hydrocarbons on temporary or permanent water bodies, etc. The location of these areas with respect to the property line is critical as they may be associated with activities on neighboring properties or activities on-site may be impacting neighboring sites.

The goal of a Phase I ESA is to gather sufficient information for property owners to make informed decisions regarding potential releases of hazardous materials and the need for further assessments, property management, options for future land use and/or remedial actions. They can also be used as baseline assessments for properties that are leased so that when comparisons with future assessments are made liability is assigned (AENV 2001a; Canadian Standards Association 2001; Pritchard 2000).

The report generated should provide an identification and evaluation of the potential risk and recommendations for further actions. If all the relevant issues have been identified and no issues of concern are declared, no further action is considered to be necessary. If however, the ESA concludes that contamination is likely present the investigator/assessor should provide the owners with recommendations for future work (Pritchard 2000).

### ***2.2.2 Phase II Environmental Site Assessment***

Phase II ESA's are generally, but not always, the next level of site investigation. Direct initiation of a Phase II ESA can occur when a release is known or suspected to have occurred, such as in the case of an underground storage tank, or in response to regulatory compliance. In these cases, the information gathered in a Phase I ESA must be incorporated into the Phase II ESA in order to establish the direction of the assessment (Canadian Standards Association 2000).

Unlike Phase I ESA's, Phase II ESA's are intrusive field evaluations that involve the collection of soil and water samples for quantitative analysis and geophysical analysis. The results of the analysis provide site-specific information that identifies, characterizes, confirms and quantifies the extent of potential liabilities highlighted by the Phase I work. The investigations may be iterative to provide definitive information and full delineation of the contamination on site. The information obtained is used by the property owners/operators to make informed decisions about property management and remedial actions. Phase II ESA's can also be used as baseline assessments for assigning future liability issues (AENV 2001a; Canadian Standards Association 2000; Kirkland 2002; Pritchard 2000).

### ***2.2.3 Phase III Environmental Site Assessment***

Phase III Environmental Site Assessments would generally be conducted following a Phase II ESA where contaminant exceedances have been identified and confirmed on a property/site. This level of investigation includes further sampling and analysis with the objective of defining the extent, degree and rate of migration of identified contaminants

into surface and ground water. The ESA should also contain sufficient information to develop a hazard assessment, exposure modeling for evaluating the potential human and environmental impacts, and explore remediation options. During this phase a remediation plan is developed, implemented and the success of the method selected would be verified (AENV 2001a; CCME 1997; Pritchard 2000).

## 2.3 DECISION MAKING IN RISK ASSESSMENT<sup>1,2</sup>

Over the past five decades the risk assessment process has undergone significant changes, shifting from a qualitative to a more quantitative direction. This shift is attributed to an increase in knowledge and understanding of the relationships that exist between adverse effects and exposure to various chemicals. Risk assessment is a valuable tool that involves the identification of potential risks to human health and the environment, and provides an indication of the degree of risk. It is this evaluation of risk that allows for the efficient allocation of resources (AIRMIC et al. 2010; Clarkson et al. 2001; Cushman et al. 2001).

Depending on the approach, the results of a risk assessment and the subsequent ranking may be quantitative, semi-quantitative or qualitative in terms of the likelihood of the occurrence and level of impact. Most organizations assess likelihood and consequences as high, medium or low and incorporate these into a classification system that will enable them to identify which strategies to apply (AIRMIC et al. 2010). Many companies and municipalities own a number of sites and as they cannot all be remediated at the same time, a scientifically defensible system to prioritise or rank these sites is needed.

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<sup>1</sup> This section is an extension of the published peer reviewed paper by Zhang, K., Kluck, C., and Achari, G. (2009). "A Comparative Approach for Ranking Contaminated Sites Based on the Risk Assessment Paradigm Using Fuzzy PROMETHEE." *Environmental Management*, 44(5), 952-967.

<sup>2</sup> This section is an extension of the published peer reviewed paper by Zhang, K., Achari, G., and Kluck, C. (2008). "Uncertainty Representation in Health Risk Assessment of Contaminated Sites." In: *Proceedings of the GeoCongress 2008: Characterization, Monitoring, and Modeling of GeoSystems* A. N. Alshawabkeh, K. R. Reddy, and M. V. Khire, eds., American Society of Civil Engineers, New Orleans, Louisiana, 926-933.



Currently, there is no universal classification system although principal methodologies for conducting risk assessments are provided by the United States Environmental Protection Agency (USEPA), and the Canadian Council of Ministers of the Environment (CCME) through the release of guidance documents (Cushman et al. 2001). However, these regulatory bodies also indicate that although the assessment process is standardized the results obtained contain a high degree of conservatism for the purpose of public safety and over-estimate the true risk associated with the site under investigation. While the absolute number obtained from the standardized assessment process provides a means of comparing and ranking several contaminated sites, the *significance* of the number is lost due to the over-estimation.

The Canadian government recommends a tiered approach to assessing and mitigating the risk at contaminated sites that combines national generic guidelines, site-specific objectives and site-specific risk assessment. Each tier is more complex and builds on the information of the preceding level(s) (Gaudet et al. 2001). However, as long as the method applied incorporates the source-pathway-receptor approach, and is scientifically defensible, the results of the investigation can be used in determining the actions that follow, such as active site cleanup, monitoring or closure (Cushman et al. 2001).

## **2.4 SCORING AND RANKING SYSTEMS IN RISK ASSESSMENT**

There are several systems that can be used to score and rank contaminated sites. They range from simple scoring systems to more complex, quantitative methodologies. The common feature of all of the systems is that they are based on a source-pathway-receptor mode of analysis.

### ***2.4.1 CCME National Classification System for Contaminated Sites (NCSCS)***

The CCME National Classification System for Contaminated Sites was originally developed in response to “a growing public concern over the potential environmental and human health effects associated with contaminated sites” (CCME 1992). The system was designed to promote consistency in property evaluations and to facilitate document

control measures. A revised scoring system was released in 2008 that is simpler to use, more objective and is more inclusive of the magnitude and quality of information available (CCME 2008).

The NCSCS uses an additive system that assigns numerical values to site characteristics under specific categories according to their potential or actual contribution to the risk of a site. These categories include contaminant characteristics, migration potential and exposure. They are considered to be equal contributors to the overall score of 100 points and are assigned weights of 33, 33 and 34 points, respectively. The process is designed to mimic the results of a traditional hazard assessment that follows the source-pathway-receptor chain of events. The sites are scored based on their individual characteristics and the amount of known information available, and not compared relative to another. Once scored, the site is classified into one of five categories; the higher the score, the greater the priority for action. A certainty score is also associated with the result and serves as an indicator of the confidence of the ranking.

While the NCSCS serves as a scientifically defensible screening tool, it does have some limitations in its applications(CCME 2008):

1. The system does not address sites with significant marine or aquatic components and it is recommended that the NCSCS not be used as the only method for classifying these sites.
2. It is not designed to provide a quantitative risk assessment but rather to serve as a screening tool that can be used for determining the need for action.
3. It requires that the minimum of a Phase I ESA be available in order to conduct the classification. When dealing with a large number of properties, Municipalities are still faced with prioritizing those sites for Phase I ESA's prior to application of the NCSCS.

4. It recommends that experienced professionals with appropriate technical expertise be consulted in the completion of the exercise, further compounding expenditures associated with site assessment and classification and delaying time for action.

#### ***2.4.2 Washington Ranking Method***

The Washington Ranking Method is a quantitative method for ranking hazardous sites using a multiplicative and additive algorithm to obtain an overall site score between 1 and 100. The scoring system evaluates data pertaining to contaminant characteristics, migration potential and exposure. A combined total of seven pathways are examined for evaluating relative human and environmental risks. The ranking obtained is not designed to be equivalent to a risk assessment, but provide a comparison of the sites based on relative risk, e.g. Site A poses higher risks than Site B. As with the aforementioned methodologies, the model relies on information available from site assessments to assess the potential risk posed by the contaminated site (Robb 1990; State of Washington 2009).

#### ***2.4.3 Waste Minimization Prioritization Tool (WMPT)***

The WMPT was released in 1997 by the United States Environmental Protection Agency to meet the objectives of the EPA's Waste Minimization National Plan: to reduce the overall amounts of waste generated and more specifically the more toxic and persistent of those waste compounds. The WMPT is designed as a rule-based system that prioritizes chemicals for further action based on their persistence, bioaccumulation and toxicity tendencies (Pennington and Bare 2001; Ralston et al. 1999; USEPA 1997c; 2007). It is a quantitative scoring algorithm that can be used for a screening-level risk based ranking of chemicals. The overall score generated reflects the potential of most hazardous chemical known or suspected to be present at a site to pose an environmental or human health risk. While the methodology is consistent with the risk assessment paradigm that guides risk assessment practices, it is used primarily for the identification of contaminants of concern. The advantage of the WMPT is that this method can be carried out even if insufficient data is available (USEPA 2007). The disadvantage is that the limited scoring

system cannot adequately identify the difference between the chemicals (Ralston et al. 1999; USEPA 1997c).

#### ***2.4.4 Human Health Risk Assessment (HHRA)***

Health risk assessment of contaminated sites is a process whereby scientific data on toxicological effects from animal studies and human epidemiology are used to quantitatively and qualitatively predict the potential incidence of adverse effects in a specific human population and characterize that risk. There are four major components involved in the human health risk assessment process: exposure assessment, hazard identification, dose-response assessment, and risk characterization (Hansson and Rudén 2006; Paustenbach 2002; USEPA 1989). While the process relies on as much scientific data as available, the use of default assumptions, models to estimate missing values, surrogate data and/or expert judgment continues to play a significant role (USEPA 2004a). In their investigation of the risk decision process, Hansson and Rudén (2006) identify that while risk assessment is the major link between science and policy, there is uncertainty in the numerical results and when combined with a high degree of flexibility and reliance on expert judgement, the process becomes inconsistent and unsystematic in all aspects. The EPA, however, stipulates that the measures utilized in the risk assessment process provide only conditional estimates of risk based on data available and assumptions made, and that uncertainty about the numerical results will range from least an order of magnitude or greater. The process is considered acceptable as it prevents the potential for underestimation of risk and thereby serves to protect the most sensitive populations (USEPA 1989).

##### **2.4.4.1 Exposure Assessment**

The exposure analysis component of risk assessment involves the qualitative or quantitative estimation and determination of the intensity, frequency, duration and route of potential human or animal exposure to the presence of chemicals in various environmental media (i.e. soil, air, water, food), and the uncertainties in all estimates.

The procedure for conducting an exposure assessment generally follows three steps

(Paustenbach 2002; USEPA 1989):

- 1) characterize exposure setting such as physical environment and potentially exposed populations;
- 2) identify the most likely exposure pathways from source to exposure point and route; and
- 3) quantify the exposure by combining exposure concentration with various intake variables.

In order to quantify exposure estimates, chemical intakes are estimated for each possible exposure pathway associated with each form of contaminated media. This is achieved by combining variables such as chemical concentration, contact rate (amount of contaminated medium contacted per unit time or event), exposure frequency and duration, average body weight over the exposure period, and the time period over which the exposure is averaged into a single formula:

**Equation 2–1: Exposure Estimate (Intake)**

$$Intake \left( \frac{mg}{kg} \right) = \frac{C \times CR \times EF \times ED}{BW \times AT}$$

where, C = Chemical concentration (mg chemical per kg soil or litre water)

CR = Contact rate (i.e. litres/day)

EF = Exposure frequency (days/yr)

ED = Exposure duration (days)

BW = average body weight (kg)

AT = average exposure time (days)

The specific value used for each of the variables is selected from a range of possible values that when combined are to provide an estimate of the reasonable maximum exposure for that pathway. The concentration term is generally the 95<sup>th</sup> or 90<sup>th</sup> percent upper confidence limit on the arithmetic average of the contaminant measured from site samples. However, if there is great variability in the measured or modeled values the maximum detected is used. This increases the amount of uncertainty associated with the estimated intake. As for the other variables, if there is inadequate specific information

available the 95<sup>th</sup> percentile of statistical data can be used as default values and are available in the *Exposure Assessment Handbook* (USEPA 1997b).

There are numerous types of uncertainties inherent in the exposure assessment process including the chemical concentrations present in the environment, magnitude of human exposure (i.e. the number and type of people likely to be exposed), the number of possible exposure pathways, time-activity patterns of different groups, modeling of contaminant fate and transport in the environment, and identifying the link between chemical source and receptor (Paustenbach 2002).

#### 2.4.4.2 Hazard Identification

Hazard identification is the first step in assessing toxicity. It is a qualitative description of the ability of a particular chemical to cause an increase in frequency of a specific health condition in human and/or non-human receptors and is represented by the strength of evidence. The process relies on information obtained primarily through controlled laboratory experiments involving various animal species or through a limited number of epidemiological studies (Langley et al. 2002; USEPA 1989).

Since the majority of data is obtained through animal studies, the primary uncertainty associated with hazard identification is interspecies extrapolation. In laboratory studies, high dosages are generally administered to the subject species and the effect is observed. Once an effective dose is identified, extrapolation to a dose that humans would most likely be exposed to in the environment is performed introducing another significant source of uncertainty and potential error. The error arises when some chemicals (i.e. methanol) have a low toxic effect on some laboratory animals yet are significantly more toxic in humans (Parekh and Dearfield 2007; Paustenbach 2002). Differences in uptake rate, mode of action and target organ susceptibility are known to account for effects observed in humans vs. laboratory animals. To portray the strength of evidence for human carcinogenicity a weight-of-evidence classification is utilized which spans from a strong positive to a strong negative. The classification/ranking scheme varies with the country of origin (see Table 2-1). There are also differences in the effects observed as a

result of exposure routes. For example, hexavalent chromium does not pose a hazard if ingested but is carcinogenic if inhaled. These uncertainties are typically accounted for in the dose-response process (Gaylor and Kodell 2000; Parekh and Dearfield 2007).

**Table 2-1: Human Carcinogenic Weight-of-Evidence**

| Strength/Type of Evidence  | Country/Organization of Origin      |                    |                           |                     |
|--|-------------------------------------|--------------------|---------------------------|---------------------|
|  | CEPA <sup>II</sup><br>(Muller 2002) | USEPA <sup>+</sup> |                           | IARC<br>(IARC 2010) |
|  |                                     | (USEPA 1989)       | (USEPA 2005)              |                     |
| Strong   | I                                   | A                  | “known /<br>likely”       | Group 1             |
| Probable   | III B?                              | B1/B2              |                           | Group 2A            |
| Possible   | II?                                 | C                  | “cannot be<br>determined” | Group 2B            |
| Unclassifiable   | III (except IIIB)                   | D                  |                           | Group 3             |
| Probably not   | V, IV?                              | E                  | “not likely”              | Group 4             |
| <sup>+</sup> In 1996, the USEPA changed their ranking scheme from an alpha-numeric one to a descriptive one, but the majority of agents are still under the old scheme. (Muller 2002)<br><sup>II</sup> Canada’s scheme is similar to the International Agency for Research on Cancer (IARC) but consists of more categories such as genotoxic and non-genotoxic carcinogens. (Muller 2002) |                                     |                    |                           |                     |

#### 2.4.4.3 Dose-Response Assessment

Dose-response assessments comprise the second step of estimating toxicity. It is a quantitative method that considers factors such as the intensity of exposure, age, lifestyle, sex, etc. of the exposed population (Paustenbach 2002; USEPA 1989). It utilizes toxicity values such as reference doses for non-carcinogenic substances and slope factors and weight-of-evidence classification for carcinogenic substances to estimate the potential for adverse effects as a function of exposure. The dose-response assessment usually requires interspecies extrapolation, intraspecies extrapolation (accounting for population heterogeneity), a dosage extrapolation (high to low), as well as professional judgement.

To evaluate the non-carcinogenic effect, a reference dose (RfD) is determined based on the highest concentration/dose of a chemical tested that does not produce an adverse effect. This dosage is known as the no-observable-adverse-effect-level (NOAEL) or the lowest-observed-adverse-effect level (LOAEL) and is reduced through a series of uncertainty factors and a modifying factor to account for the aforementioned extrapolations and assumptions (Schoeny 2007). The uncertainty factors range in value from 1 to 10 with 10 being the default. The modifying factor reflects professional judgement and ranges from 0 to 10, with 1 as the default. Multiplying several uncertainty factors at their maximums and, however, lead to compounding conservatism in the resulting RfD value and thus the USEPA recommends that a maximum of 3000 be used for the product of 4 uncertainty factors, and a maximum of 10000 be used for 5 uncertainty factors (Gaylor and Kodell 2000; USEPA 1989).

Carcinogenic effects are based on a toxicity/slope factor (SF) determined quantitatively from the relationship between dose of and response to a given chemical exposure. The slope factor is a considered the reasonable upper bound estimate (95<sup>th</sup> or 90<sup>th</sup> percent confidence limit) of the probability that an individual will develop cancer as a result of life-time exposure to a known or potential carcinogen. As epidemiological data is limited, animal data is generally used as the basis for extrapolation with the human dose being equivalent to the animal dose with respect to body surface area exposed. Depending on the units employed the animal dose is generally scaled by a ratio of human to animal body weight raised to the power of 2/3 (mg/day units) or animal to human body weight raised to the 1/3 power (mg/kg-day units). Laboratory testing can be performed on several species at a given time and if more than one exhibits adverse effects either the species closest to humans or the most sensitive species is selected (Gaylor and Kodell 2000; Paustenbach 2002; USEPA 1989).

#### 2.4.4.4 Risk Characterization

Risk characterization is the final stage of the human health risk assessment process. It involves integrating information obtained in the exposure, hazard identification and dose-



response assessments to obtain an indication of risk severity. Risk severity is determined through the quantification of carcinogenic and non-carcinogenic effects by combining the intakes for all exposure pathways with the respective chemical specific slope factor or reference dose.

Contaminated sites contain multiple chemicals. The concentrations and compositions of chemicals identified at a site does not remain constant as they degrade based on their media specific half-life, leaving chemicals either in original form (i.e. as released) or in some proportion degraded to daughter products. Accounting for multiple chemical exposures is accomplished through the concept of additivity. The total carcinogenic risk for an individual exposed to a contaminated site is the sum of the individual chemical risks (Health Canada 2004a; USEPA 1989),

**Equation 2–2: Total Carcinogenic Risk**

$$Carcinogenic\ Risk_{Total} = \sum_{i=1}^n Intake_i \times SF_i$$

and the value obtained represents a probability of exhibiting cancer (ie.  $10^{-6}$ , or one in a million chance). The total non-carcinogenic effect is also known as the Hazard Index (HI) and is computed similarly through the summation of pathway and chemical specific hazard quotients (Health Canada 2004a; USEPA 1989).

**Equation 2–3: Total Non-Carcinogenic Risk (Hazard Index, HI)**

$$Hazard\ Index, HI = \sum_{i=1}^n HQ_i = \sum_{i=1}^n \frac{Intake_i}{RfD_i}$$

The resulting risk value differs from the carcinogenic risk value in that it indicates the *potential* of non-carcinogenic toxicity occurring and **not** its probability.

The assumption of additivity, however, does not take into account the possible synergistic or antagonistic effects of chemical mixtures (Krewski and Thomas 1992). Synergistic

effects refer to the augmenting of the risk wherein two or more compounds react together to produce another compound of significantly higher toxicity compared to the original compound. An example of this is seen in the water disinfection process when added chlorine reacts with organic matter in the water to produce trihalomethanes, which are known to produce adverse health effects. Antagonistic effects result in the overall risk value being less than expected with additivity due to the negating/neutralizing effects of the chemical mixtures.

From the above discussion, it is evident that the uncertainties with risk characterization are a culmination of the uncertainties associated with site conditions, exposure assessments and the toxicity criteria. As each stage of the risk assessment process provides conservative information/data the propagation of uncertainties results in an overly conservative final risk estimate (Paustenbach 2002; USEPA 1989).

#### ***2.4.5 Ecological Risk Assessment (ERA)***

Ecological risk assessment is a dynamic, interdisciplinary field encompassing environmental toxicology, ecology and environmental chemistry. It evaluates the likelihood that an adverse ecological effect may occur as a result of exposure to one or more stressors (USEPA 1997a; 1998). The paradigm is similar to that used in human health but tends to be more flexible in response to design needs. The basic goal of ERA's is the characterization of effects and exposures. The process consists of three main steps: problem formulation, analysis and risk characterization.

The first step is *problem formulation* and involves the identification of the problem and the development of an action plan for analyzing and characterizing the risk. Information available on sources, stressors, effects and ecosystem and receptor characteristics are examined and incorporated into the action plan. It is during this step that the assessment and measurement endpoints for the ERA are identified (MacDonell and Holoubek 2001). Assessment endpoints should define the valued ecological entity at a site (e.g. species, resource or habitat) and the characteristic of the entity to protect (e.g. reproductive success) and be measurable. This step is completed with the development of an analysis

plan that delineates the assessment design, data needs, measures and analytical methods (Paustenbach 2002; USEPA 1997a).

The *analysis step* is the exposure assessment step wherein the stressor and response relationship are investigated (Paustenbach 2002; USEPA 1997a). For each complete exposure pathway, route and contaminant an ecotoxicity value should be used. Currently values for surface waters and sediments based on direct exposure routes are available. According to the USEPA guidelines, ecotoxicity values should represent a no-observed-adverse-effect-level (NOAEL) for chronic exposures but, in the absence of this data the lowest-observed-adverse-effect-level (LOAEL) may be used (USEPA 1997a). Environment Canada, however, recommends the use of acute toxicity studies over chronic studies due to the availability of data for a larger number of substances (Canadian Environmental Assessment Agency (CAEE) 2007; Environment Canada 2003; 2006a).

*Risk characterization* is the third and final step where risk estimation occurs. A quantitative risk level is estimated using the exposure estimates and the screening ecotoxicity values identified in the analysis step (MacDonell and Holoubek 2001). In the event of multiple contaminant exposures, the potential ecological concern at a site can be considered to be the sum of the individual effects. That is, additivity is assumed as with the human health risk assessment. The risk calculation is to be a conservative estimate to ensure that potential threats have not been overlooked.

#### ***2.4.6 Comparative Risk Assessment (CRA)***

Comparative Risk Assessment is comparative risk paradigm that was developed in the early 1980's and has emerged as a central tool for evaluating public health concerns, environmental management strategies, and especially for prioritizing environmental and ecological issues for various groups. CRA are performed through the simultaneous analysis, evaluation or ranking of multiple hazards and their associated risks (Andrews et al. 2004; Shatkin et al. 2004).

The CRA has been developed as a framework to provide site managers with a degree of hazard associated with one site compared to others under investigation. A relative score is obtained and minimizes any negative connotations generated with absolute risk values (Shatkin et al. 2004). The framework consists of the following steps (Shatkin et al. 2001; USEPA 2003):

1. Define the problem to be ranked
2. Determine the risk posed by each problem and identify the appropriate ranking criteria
3. Rank the risks (a hierarchical approach is typically used)
4. Report the data and ranking
5. Identify and rank strategies for risk reduction
6. Implement strategies
7. Monitor results and adjust response as required.

Comparative risk assessment is a useful tool for risk-based prioritization. Weighting factors can easily be assigned in the second step of the ranking process. The stepwise process builds from raw data to a prioritized ranking (Shatkin et al. 2001).

CRA is a flexible process and defining the goal of a CRA is important because the goal shapes the process and its applicability (Andrews et al. 2004). The strength of CRA appears to be in the ability to develop public-policy in a consistent manner and to encourage stakeholder input (McCallum and Santos 1997).

#### ***2.4.7 Multiple Criteria Decision Analysis (MCDA)***

Multiple Criteria Decision Analysis (MCDA) is a decision making methodology based on the premise of assisting a decision maker through the decision process via explicit formalized models (Figueria et al. 2005a; Roy 2005; Want and Triantophyllou 2006). The basic components in any MCDA method include a finite set of actions or alternatives each of which must be explicitly described in terms of criteria or objects that must be simultaneously assessed. Ideally, the integrity of these criteria should be preserved in

their original form without any conversion (i.e. equivalencies, weightings, etc) to maintain their meaning and accurately evaluate their consequences. The results of the assessment (performance values) are typically placed in a decision matrix along with their associated criteria weights. Pair-wise comparisons are then completed to either find the best alternative or rank the alternatives in order of total preference, known as preference modelling (Figueria et al. 2005a; Ozturk and Tsoukias 2005; Want and Triantophyllou 2006).

Since the inception of preference modeling, many methods have been proposed and/or expanded to analyze the data of a decision matrix and provide some measure of alternative comparability.

#### 2.4.7.1 Analytical Hierarchy Process (AHP)

The AHP was created by Thomas Saaty in 1980 as a method for developing an evaluation model. It is based on the concept of a simple hierarchical structure where dependence of one component on another occurs in a sequential manner. The global objective is represented in the highest node/level and is comprised of a number of sub criteria located at the next level. The approach assumes the functional independence of an upper part (parent) from a lower part (child), but not the reverse. The simplest model consists of three levels: the goal, the criteria and the alternatives. The more complex the case, the more levels may be required (Bouyssou et al. 2006).

Once the hierarchical structure is developed, weights are assigned to the criteria based on preferences in pair wise comparisons. These comparisons are rated on a scale of one to nine (1 = equal; 3 = moderate; 5 = strong; 7 = very strong; 9 = extreme; even values for compromise) and the preference values are placed in a matrix (Linkov et al. 2004). The preferred criterion is given the full value assigned, and the comparator is assigned the inverse of the value (i.e. 3 versus 1/3). The final weighting for the criteria is the normalized value of the eigen vector associated with the maximum eigen value for the matrix. The same procedure is used to compare the alternatives at the next level. The

overall score is obtained by summing the products of the criterion and alternative weights/scores (Bouyssou et al. 2006; Steele et al. 2009).

Further research in this methodology has resulted in the development of the multiplicative, weighted product and fuzzy AHP models (Millet and Wedley 2002; Triantaphyllou and Mann 1995; Want and Triantophyllou 2006). Many studies have reported that the AHP methodology produces inconsistent results and rank reversals have been known to occur with alternatives that are closely similar (Dyer 1990; Millet and Wedley 2002; Perez 1995; Triantaphyllou 2001; Triantaphyllou and Mann 1995). While the AHP works on a premise that decision-making can be facilitated by structuring the problem/issue into a basic but comprehensive hierarchical structure, AHP involves human subjectivity throughout the pair wise comparisons and the introduction of uncertainty into the final decision (Tesfamariam and Sadiq 2006).

#### 2.4.7.2 Fuzzy Logic<sup>3</sup>

A preliminary fuzzy multi-objective decision making model (MODM) in conjunction with a rule-based system was developed for the ranking of contaminated sites based on information and scores used in the NCSCS and existing research on risk assessment and site ranking (Garg et al. 2004). The method identifies key objectives such as magnitude of contamination, groundwater contamination potential, contaminant migration potential, toxicity and persistence, represents them in the form of membership functions and then evaluates them using a rule-based system.

The criteria selected are typically non-interactive and their relation to the objective is non-linear. Therefore, in order to determine the importance of the criteria, membership functions are developed for each parameter and their domain is partitioned into a number of fuzzy sets or linguistic variables. The fuzzy sets reflect the cognitive state of the decision maker and are determined either based on the experience, knowledge, or through

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<sup>3</sup> This section contains excerpts from an unpublished work by Kluck, C. (Unpublished). "Application of Fuzzy Logic For the Ranking of DNAPL Contaminated Sites." University of Calgary, Calgary.

the use of frequency histograms or probability curves. The shapes of membership functions are solely at the discretion of the decision maker. Triangular functions are commonly applied due to their simplicity and trapezoidal ones are considered extensions of triangular ones representing decreased uncertainty (Adriaenssens et al. 2004; Ross 2004). Due to the subjective mode of establishing membership functions, optimization of the fuzzy model can only be achieved through trial-and-error methods. Once membership in the associated parameters is derived, their contribution to the final output is determined through the development of fuzzy rules.

Fuzzy-rules provide a means of representing knowledge by a number of *if-then* rules. The rules are generally linguistic in nature and consist of two parts: an antecedent part that states conditions on the input parameters and a consequent part that describes the corresponding value of the output (Adriaenssens et al. 2004). The antecedent parts of the rules are evaluated for their degree of fulfillment via the use of membership functions and this determines their contribution of the rule to the fuzzy set of possible output values. In MODM an antecedent proposition would be composed of propositions involving several input parameters joined together by a conjunction operation. Continuing with the contaminant toxicity objective above, an if-then statement would appear as follows: if non-carcinogenic effect is low AND carcinogenic effect is high (antecedent proposition), then contaminant toxicity is high (consequent proposition). The total number of rules required to derive a final output value is dependent upon the number partitions used to evaluate the degree of membership of the parameter. For a small number of inputs, the rules can be combined in a graphic form called a fuzzy associative memory table, or FAM table. Once a membership degree is obtained for each rule a composite membership value is evaluated using any one of a number of defuzzification techniques, the most common method being the weighted average method (Ross 2004).

The development of the membership functions for each objective is based on expert opinions or published literatures and thus is also subjective. Although the data used by Garg et al (2004) was limited in quantity and type, the results obtained were consistent with those obtained from two other methods (partial ordering and index).

To test this methodology, data from a large number of dry cleaning sites were applied to the model and an overall ranking of the sites was achieved. Once a decision value was obtained for a given contaminant those sites that exhibited tied values were further separated by removal of the objective causing the tie to occur (either the value or associated preference). This elimination process continued until either the tie was broken or no further separation could be achieved. While the application of parent-to-daughter transformation pathways provided an additional means of determining final rankings of sites, situations where unrelated multiple contaminants are present still need to be addressed. As the model is limited to evaluating the hazard associated with the groundwater exposure pathway, expansion of the model to include contamination via dermal or inhalation pathways could be achieved by adding parameters such as maximum contamination in soil and/or air to the first objective (magnitude of contamination) or by establishing separate objectives. While the analysis of the ranking data revealed that further refinement of the membership functions are required to ensure data segregation and inclusivity in the model, fuzzy modeling as a method of contaminant site ranking appears promising.

#### 2.4.7.3 Outranking Methods

Other methods that are commonly used are the “outranking” methods, primarily ELECTRE and PROMETHEE. These methods make use of binary relations on a set of potential actions to develop a preference relation between and within alternatives. (Bouyssou 2005; Want and Triantophyllou 2006) The preference value obtained is an indication that decision *a* is at least as good as *b* (Figueria et al. 2005a).

##### 2.4.7.3.1 ELECTRE

Of the family of ELECTRE models, ELECTRE II (true-criteria based procedure) and ELECTRE III (dealing with inaccurate, imprecise, uncertain or ill-determined data) are the most widely used. The basic underlying concept is to develop one or several outranking (binary) relations followed by an exploitation procedure that a set of promising alternatives that must be further analysed (Bouyssou et al. 2006; Figueria



2005; Wang and Triantaphyllou 2006). With each criteria, two distinct sets of parameters are identified; importance coefficients and veto thresholds. The importance coefficients refer to the intrinsic weight of influence in favour of an outranking whereas the veto threshold contributes weight against the outranking. These parameters are selected by the decision maker and are selected as the most convenient (best adapted) for expressing the uncertainty in the information. The exploitation procedure follows a four-step process leading to a final partial pre-order. Treatment of incompatibility conditions are subject to the decision-maker and often criticized. Implementation of the ELECTRE methods requires either the direct input of preference parameters from the decision maker or indirectly through inference from answers to a series of questions. In either case, an additional source of arbitrariness is introduced to the problem under investigation (Figueria 2005). Wang and Triantaphyllou (2006) have identified similar ranking irregularities as those seen with the AHP methodology and suggest that acceptance of recommendations obtained through the application of ELECTRE be circumspect.

#### 2.4.7.3.2 Preference Ranking Organization Method for Enrichment Evaluation, PROMETHEE

PROMETHEE methods have also evolved since their initial entry into the realm of MCDA. Their ease of use is based on the premise that all the information requested is clear and easy to define, and the method is easy to apply. Brans and Mareschal (2005) acknowledge that incomparability holds for most pair wise comparisons since when one alternative is better on one criterion the other is often better on another. The PROMETHEE methods provide a means of accounting for the amplitude of deviations between alternative comparisons, permit each criterion to be expressed in their own units and allow criteria weight allocation to reflect the decision makers' interpretation of the criterion importance to the final result. The decision maker is also able to select the most appropriate indicator for preference based on six types of preference functions. The preference function selected will indicate the appropriate parameters required (indifference threshold, strict preference threshold, and intermediate value). Then based on the pair wise comparisons either a partial ranking (PROMETHEE I) is obtained from

the preference values or a complete ranking (PROMETHEE II). A complete ranking ensure that all alternatives are comparable. A graphical profile can also be generated for all the criteria that indicate the degree to which the criterion is preferred over the others and vice versa. This information can be used to finalize the decision (Brans and Mareschal 2005). Because of the relative ease combined with the non-manipulation of original data, PROMETHEE presents a valid method for MCDA.

## CHAPTER THREE: METHOD DEVELOPMENT

### 3.1 INTRODUCTION

Management of contaminated sites is a major responsibility of any large municipality. With an increasing number of sites being identified every year combined with budgetary constraints and increasing legislative reporting requirements, municipal environmental engineers are in need of a formal methodology that follows a system of standardized practice to streamline the processes involved in the identification and prioritization of these properties.

The underlying foundation for identification and prioritization of contaminated sites is risk assessment. Risk assessment is a multi-disciplinary process based on varying quantity and quality of factual information combined with scientific theory. It provides a record of the technical basis for a decision and information that can be used to address stakeholder and public concerns (Suter et al. 2007). The results of risk analysis are an evaluation of risk in quantitative terms with a statement of expected accuracy (Roberts 1988). Risk assessment is not exact since the information used is dependent on the completeness of the data available. Therefore, all risks are relative and not absolute. Perceived risk and actual/known risk are two different but related entities and they are often difficult to differentiate to those possibly affected, such as workers and the general public. It is this perception of risk that is often the most difficult to manage since the general populace tends to focus on the numbers.

In order to avoid/reduce misinterpretation, the methodology developed should (Allen et al. 1998; National Research Council 2008):

- have a logical framework
- be consistent and transparent
- include/incorporate pertinent data, knowledge and expertise

- be able to capture, store, select and analyze the information
- be scientifically based and supported
- generate relevant reports, decision advice
- provide a means of prioritizing the potentially contaminated sites **without implying a specific risk value**

For a municipality to evaluate which of their assets are either at risk of becoming, or are contaminated beyond the limits deemed acceptable by the current regulatory bodies, the municipality must examine several aspects of each site as a part of their due diligence. The most accepted practice is a phased investigation approach wherein the objective is to gradually learn enough about the site conditions until a level sufficient information has been obtained to make an informative decision regarding the next phase. The procedure generally takes the path of an initial investigation, followed by a Phase I Environmental Site Assessment and, if necessary the more detailed and intrusive Phase II Environmental Site Assessment (AENV 2008a; Canadian Standards Association 2000; 2001; Nielsen et al. 2005; USEPA 1989).

It is this phased approach that is incorporated into the design of the decision support system (DSS). As each phase of the process involves the collection and analysis of large quantities of data in an effort to meet specific objectives and provide guidance to the decision maker, the DSS takes the form of a Multi-Criteria Decision Making (MCDM) model. When developed as such, it serves as a valuable tool for dealing with multiple objectives, multiple risks and uncertainties, and multiple stakeholders while estimating the potential impact of contaminants that can be used to rank sites and set priorities for action.

While the generalized method described in the following sections can be used for any municipality, the methodology has been developed for direct application by the City of Calgary, Alberta, Canada.

### 3.2 MODEL FRAMEWORK

The framework developed for the ranking of contaminated sites consists of a multi-layer model wherein the first level provides a coarse means of assessment (screening the sites based on readily available data, classifying and ranking) followed by a more refined, more detailed investigation and analyses in the subsequent levels. The framework (de Lemos et al. 2006) is shown in Figure 3—1 with a slight modification incorporating an additional classification category in the 3<sup>rd</sup> Level Model.

Level 1 is the initial site screening process. Information is gathered regarding the sites location, current and historical activity, zoning history and report history. Based on the analysis of this information a decision has to be made whether there is sufficient concern to further the investigation; submit to a Phase I Environmental Site Assessment (ESA). The decision process involves the implementation of a rule-based system consisting of simple IF-THEN statements to classify the site into one of three categories:

Class 1: action required - Phase I ESA recommended

Class 2I: No Further action required

Class 3: Consult environmental reports available and reclassify site as  
Class 1 or Class 2I

Level 2 pertains to those sites having undergone a Phase I ESA. The decisions involved at this level are dependent on the recommendations of the report. If sufficient evidence exists to indicate potential contamination, the consultant's report will recommend further investigation, otherwise if the site does not exhibit any issues of concern it will be considered 'clean'. Thus, the site is classified into one of two categories:

Class 1: Phase II ESA recommended

Class 2II: no further investigation

Level 3 is the final screening and assessment portion of the Framework. At this level the data acquired through the Phase II ESA investigations is incorporated into the database, combined with newly screened data and subjected to the mathematical computations

intrinsic to a multi-criteria decision making (MCDM) model. The MCDM focuses on combining the results from the investigation of five major criteria (1)Potential Human Health Impact, (2)Potential Ecological Impact, (3)Legislative compliance, (4) Potential Political Impact, and (5) Remediation and/or Monitoring Cost to rank and classify the contaminated site into one of several site management categories:

Class A: Remediation required immediately

Class B: Remediation required but can be delayed temporarily

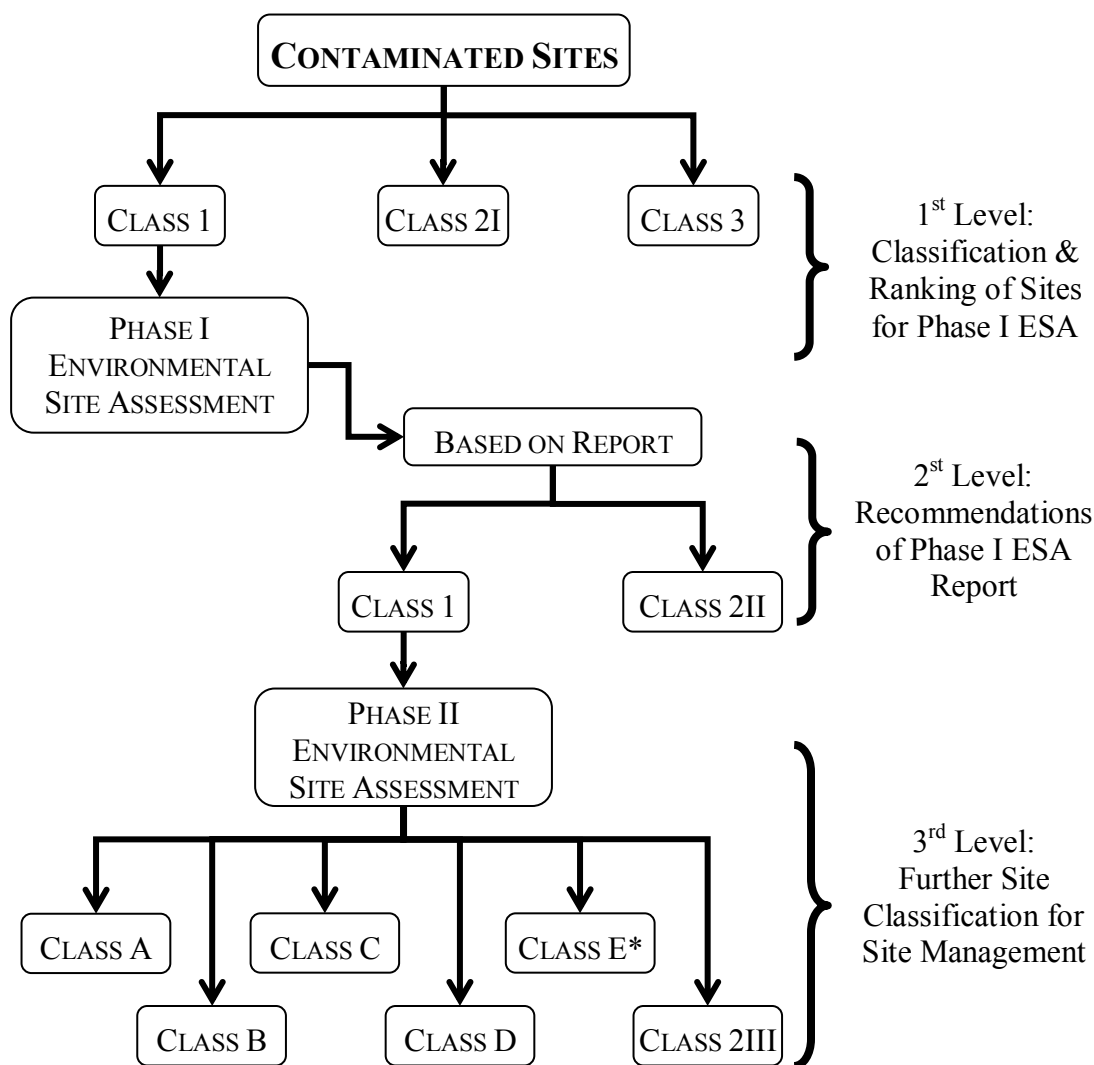
Class C: Long term monitoring (Risk Management) required

Class D: Low risk, intermittent monitoring required,

Class E: Further investigation required (insufficient data), and

Class 2II: no further investigation required.

It should be emphasized that while the DSS (Rule-Based and MCDM models) developed does invoke the use of qualitative and/or quantitative risk assessment protocols, the results obtained are representative of POTENTIAL impact only and serves as a detailed screening tool for identification and prioritization of sites and identifying actions to be taken.



**Level 1 Classification:**

- Class 1: Action Required (Phase I ESA recommended)
- Class 2I: No Action Required
- Class 3: Review Reports & Reclassify as Class 1 or Class 2I

**Level 3 Classification:**

- Class A: Remediation required immediately
- Class B: Remediation required but can be delayed temporarily
- Class C: Long Term monitoring (Risk Management) required
- Class D: Intermittent monitoring required (low risk)
- Class E: Further investigation required (insufficient data)
- Class 2III: No further investigation required

**Figure 3—1: Model Framework**

## CHAPTER FOUR: **LEVEL 1 - CLASSIFICATION & RANKING OF SITES FOR PHASE 1 ENVIRONMENTAL SITE ASSESSMENTS**

### **4.1 INTRODUCTION**

Large municipalities are entrusted with management of thousands of properties while working under restricted budgets. Therefore, there is a need for efficiently identifying and prioritizing those properties that may have been exposed to activities and/or events which could have resulted in some level of contamination. Level 1 of the multi-level Decision Support System Model Framework (Figure 3-1) involves the identification, classification and ranking of sites *for* Phase I Environmental Site Assessments (ESA).

A Phase I ESA is a non-invasive investigative examination of a property to determine the existence of a potential environmental concern and any associated contaminants of potential concern. It consists of a document search for historical and current activities, land use, previous history of contaminant spills combined with a physical site visit to visually identify areas of potential concern (stressed or lack of vegetation, oily residues in water bodies or on soil) and possibly interviews with current/previous site managers. It is the result of this investigation that determines the next level (AENV 2001a).

Municipalities, having access to several internal and external databases, are able to obtain a significant amount of information similar to that gathered in a Phase I ESA for a preliminary screening of their sites. It is this preliminary screening that forms the basis of the Level 1 Classification & Ranking methodology.

The chapter provides the methodology developed for the first level of the DSS; Classification and Ranking of Sites for Phase 1 ESA's. It will describe the screening information required for the process, information recommended for documentation purposes, and the classification and scoring system. A case study is provided to illustrate the application of this portion of the DSS.



## 4.2 SITE SCREENING

The first step in developing the DSS involves site screening. Site Screening involves the collection and tabulation of relevant environmental liability information on property owned and/or operated by the municipality. Each site investigated will have a unique set of circumstances that need to be examined and documented. The information collected must be sufficient in quantity, specific, accurate, precise, complete, comparable and representative of the site conditions. Generating sufficient, quality data assures certainty, and increased confidence in conclusions regarding the site environmental conditions (AENV 2008a; Nielsen et al. 2005).

The site specific data collected during the screening process is typical to that required by an environmental site characterization program. It should include the site's spatial (i.e. size, location) and physical conditions (i.e. geology, hydrogeology), contaminant-related information such as potential sources and nature (physical and chemical properties) of the most commonly associated contaminants present. In order to be able to evaluate regulatory compliance, contaminant transport pathways need to be identified along with location of potential receptors and routes/points of exposure; receptors should include water supply wells (municipal, domestic, agricultural and industrial) and surface water bodies, buildings with basements, utility corridors, and sensitive ecological areas (AENV 2008b; Nielsen et al. 2005).

The information collected will build a baseline of knowledge that encompasses both past and current activities on a site that could contribute to potential contamination. It is based on this information that the sites are to be classified and scored, providing a means of prioritizing action to be taken on the potentially contaminated sites. It should be noted that while the data collected may not be specifically used in the Level 1 methodology, it does assure comprehensive documentation of each site.

Table 4-1 provides a list of typical property descriptors that a municipality would use for spatially defining a property. Two addresses (current and historical) may be required if a property's location has been changed due to incorporation into the city limits or due to

subdivision of a larger property into smaller parcels. The historical address may have an environmental history that a current address would not and would be a contributing factor to the assessment of the property(AENV 2008a).

**Table 4-1: Spatial Property Descriptors**

|   |                             |
|---|-----------------------------|
| Review Date   |                             |
| Address   | Current main street address |
|   | Historical Address          |
| Unique Property Identification Number (if applicable) |                             |
| Map Section   |                             |
| Community District                                    |                             |
| Ward Number   |                             |
| Site Name   |                             |
| Site Surface Area                                     |                             |
| Land Use Designation (s)                              |                             |
| Property Use Designation (s)                          |                             |
| Buildings   | Presence                    |
|   | Quantity                    |
| Sources of all data collected                         |                             |

Land Use designations are generally an alphanumeric code that indicates the zoning defined in the by-laws of a municipality. For example, the City of Calgary uses an I-2 designation to represent a General Light Industrial District that allows a range of similar uses that would not have an adverse impact on neighbouring non-industrial land uses (The City of Calgary 2008 (May 2010 Update)-b). Property use designations are more descriptive terms that represent the actual usage of the property. Using the same land use

zoning example, the permitted uses range from *recreational* (parks and playgrounds) to *commercial* (grocery stores, greenhouses, auto body shops, laboratories) to *industrial* (manufacturing good or products). Multiple land and/or property use designations may exist for a property and a reasonable number of these should be identified and recorded. Again, the information gathered during this review must be refer back to the first property use that may have affected the site's environmental condition or to the extent that historical information allows (AENV 2008a).

In as much as activities occurring onsite may be the primary causative agent, the activities of neighbouring properties may also have a contributing role in the overall condition of the site. It is recommended that a "buffer zone" be established surrounding the subject property wherein the activities of the neighbouring properties can be examined and documented. It is important to identify as many onsite and offsite activities/sources as feasible when screening a site. Table 4-2 and Table 4-3 provide a list of potentially contaminating sources and activities that can be readily identified through the screening process. The activities listed in Table 4-3 are not considered to be all-inclusive but are those identified as occurring within and/or near the boundary limits of The City of Calgary (The City of Calgary 2008).

Information regarding the geological units, type of soil, surface and ground water bodies is available through maps and reports provided by federal, provincial and territorial agencies(AENV 2008a). These documents are further supplemented by municipality development documents wherein man-made surface water features (ditches, reservoirs, man-made lakes, storm water outfalls, etc.) were approved for development and are fully delineated. For the purposes of the preliminary screening, the information regarding the surficial geology of the site was limited to course (gravel), less course (sand) and fine (other) soil type descriptions. It is believed that these generalized categories would be sufficient to indicate transport potential. According to Alberta Environment's Tier 1 Soil and Groundwater Remediation Guidelines, all existing and potential uses of groundwater and surface water, including their locations with respect to the site, should be identified and documented; water uses within 100m upgradient and 300m downgradient of the site

is recommended when groundwater flow direction is known (AENV 2008b). Further to location, the type of water body is significant and should also be identified based on use. Table 4-4 provides the types of geologic and hydrogeological screening data required for the Level 1 comparative site analyses.

**Table 4-2: Screening Data for Potentially Contaminating Sources**

|                   |   |   |
|-------------------|---|---|
| Tanks             | History of Tanks (Yes/No)                                     |   |
|                   | Storage Tank Type   | Underground (UST)<br>Aboveground (AST)<br>Unknown |
|                   | Quantity of Tank Types (Current and/or Historical)            |   |
|                   | Total overall number of Historical AND Current Tanks          |   |
|                   | Shortest Distance from Tank containing parcel to Subject Site |   |
| Landfills         | Landfill type   |   |
|                   | Landfill Name   |   |
|                   | Distance to Landfill  |   |
| Foreign Utilities | Present (Yes, No, n/a)  |   |
|                   | Utility Type (Pipeline, Well)                                 |   |
|                   | Well Type (oil, gas, both)                                    |   |
|                   | Distance to Closest Well and/or Pipeline                      |   |

**Table 4-3: Screening Data for Potentially Contaminating Activities (PCA's)**

| Total # all PCA's        |   |   |
|--------------------------|---|---|
| Activity Category        | Petroleum Handling System                   | Gas station, auto/truck repair, shop/garage; petroleum bulk storage/bulk distribution facilities; site containing petroleum storage tanks for fuelling equipment  |
|                          | Dry Cleaners                                |   |
|                          | Railway Operations                          | Railway Operations; Rail yards (not including Railway tracks)   |
|                          | Miscellaneous 1                             | Wood preserving or processing; manufacturing or processing of plastics/Styrofoam, sulphur products, tires, rubber products, carpets, metals/metal products, paper/paper products, bricks, wire/wire rope  |
|                          | Auto Body Shops & Junkyards                 | Auto body shop or garage; metal plating/finishing; auto wrecking/scrap metal; machining   |
|                          | Road Operations                             | Snow Storage/disposal; Roads maintenance and salt storage yards   |
|                          | Animal Processing and Fertilizer Production | Slaughter house or other food processing; agricultural land with livestock operations; tannery; fertilizer; herbicide and pesticide products; land application of waste sludge's  |
|                          | Miscellaneous 2                             | Battery Storage, maintenance, recycling or disposal; electric equipment repair; asphalt; concrete, cement, gypsum or lime products; coal facilities; photographic industry; explosives and firing ranges; armouries and other military facilities; uncontrolled waste disposal and sewage treatment; airports or aircraft maintenance facilities; railway tracks; hospitals, pharmaceutical or medical industry; funeral services; distilleries or breweries; incinerators or boilers/heat exchange industry; commercial refrigeration or air conditioning; insulating material; tar and roofing materials; milling |
|                          | Undefined                                   |   |
| Distance to Site         |   |   |
| Specific Area of Concern |   | Bus fuelling, active/inactive landfill, sand/gravel pit, railway, gas station, machine shop, substation(transformers), dry cleaners, cemetery, hospital, sewage treatment, chemicals, explosives, firing range, salt storage yard, etc.   |
| Sources of Information   |   |   |

**Table 4-4: Geologic and Hydrogeologic Screening Data**

|                   |   |   |
|-------------------|---|---|
| Surficial Geology | Gravel  |   |
|                   | Sand  |   |
|                   | Other   |   |
| Hydrology         | Total overall number of water bodies/water wells      |   |
|                   | Type of Onsite Water Body                             | Water well                                    |
|                   |   | Wetland                                       |
|                   |   | River   |
|                   |   | Creek   |
|                   |   | Lake  |
|                   |   | Manmade Lake                                  |
|                   |   | Reservoir                                     |
|                   |   | Irrigation Canal                              |
|                   |   | Storm Outfall Channel/Pond                    |
|                   |   | Drainage Ditch                                |
|                   |   | Undefined                                     |
|                   | Water Well (yes/no)                                   |   |
|                   | Type of Water Well                                    | Domestic                                      |
|                   |   | Industrial                                    |
|                   |   | Agricultural                                  |
|                   |   | Undefined                                     |
|                   | Type of Offsite Water Body                            | Potable                                       |
|                   |   | Agricultural/Recreational                     |
|                   |   | Ecological                                    |
|                   |   | Other   |
|                   | Closest Distance of Water Body / Well to Subject Site |   |
|                   |   | Total number of Water bodies in each category |

Over the years, municipalities have performed several environmental investigations on properties they own/operate either as part of “due diligence” or as deemed necessary based on the circumstances at the time. Thus, they have accumulated a number of reports associated with owned/operated, newly acquired and/or neighbouring properties at varying levels of investigative detail; some properties may have more than one report, whereas others may have none. Level 1 of the Model Framework is to provide a means of identifying those sites that require a Phase 1 ESA and thus the environmental report history forms an important part of the screening criteria. Table 4-5 indicates the types of environmental reporting that should be identified.

**Table 4-5: Environmental Report History Screening Data**

| Report(s) Available (Yes/No)                      |   |
|---|---|
| Environmental Investigation Completed             | Remediation Plan                                    |
|   | Risk Management Plan                                |
|   | Phase III Environmental Site Assessment             |
|   | Phase II Environmental Site Assessment              |
|   | Further Work/ Supplemental Investigation            |
|   | Combined Phase I & II Environmental Site Assessment |
|   | Tank Decommissioning/Excavation/Sampling Program    |
|   | Phase I Environmental Site Assessment               |
|   | Undefined Environmental Site Assessments            |
|   | Other Reports                                       |
| Other documents (correspondence, etc)             |   |
| Geotechnical Investigation (Yes/No)               |   |
| Distance to site with most detailed investigation |   |

### 4.3 CLASSIFICATION FOLLOWING SITE SCREENING

Once the sites have been screened and the database generated, the next stage of the Level 1 methodology can be initiated: classification. Classification following site screening involves analysis of the primarily linguistic data to sort each screened site one of three categories:

Class 1: Action required - Phase I ESA recommended

Class 2I: No Further action required

Class 3: Consult environmental reports available and reclassify site as  
Class 1 or Class 2I

When data is linguistic in nature mathematical relationships are non-existent. Thus, an alternate means of analysis is required wherein the data can be used without manipulation to provide the final outcome. Rule-based systems can be used to map/connect linguistic input to output through the use of conditional statements that capture information from a knowledge base and draw conclusions given those facts. The conditional statements consist of a series of IF-THEN rules (Abraham 2005). The general format of these statements is expressed as:

*IF* premise (antecedent), *THEN* conclusion (consequence).

In the case of multiple inputs the statement can be clearly represented with the use of the Boolean operators AND and OR:

*IF* premise<sub>1</sub> AND premise<sub>2</sub>, *THEN* conclusion<sub>1</sub>

*IF* premise<sub>1</sub> OR premise<sub>2</sub>, *THEN* conclusion<sub>2</sub>

The rules developed are based on the information gathered in the screening process, and should reflect the needs/requirements set forth by the municipality. The criteria selected are:

- property size,
- the existence of environmental reports for the owned/operated property and/or properties within a designated buffer region (i.e.100m), and
- the presence of potentially contaminating activities (PCA), both on- and off- site.



The “property size” criterion is selected to sort out those properties that are less than a specified area (grassy boulevards, intersection corners, etc.) as they would be considered “insignificant” compared to the remaining properties from a budgetary perspective.

The “existence of environmental reports” indicates that some form of investigation has already been done and thus, further action on that site can be delayed until the reports have been reviewed.

Ideally, the screened data should be used in its original form to remove any misinterpretation or introduction of bias into the analysis. However, when dealing with the large variety of PCA’S that can be identified (Table 4-2 and Table 4-3) some form of grouping is necessary to streamline the process. The grouping should combine the nature of the activity/source and the associated potential risk posed by the chemicals. For example, underground storage tanks would be considered a higher risk than above ground storage tanks primarily because of their proximity to groundwater and early leakage detection is more difficult. Dry cleaners have historically used dense non-aqueous phase liquids (DNAPL’s) such as trichloroethylene (TCE), perchloroethylene (PCE) as their cleaning solvents. These solvents are both immiscible in water and denser than water causing them to sink below the water table when spilled in significant quantities. When these compounds degrade, the daughter products (i.e. vinyl chloride, dichloroethylene) are more toxic than the parent compounds and thus, are more harmful to the environment. DNAPL cleanup is more difficult and more costly (Pankow and Cherry 1996; Schwillie 1988). Therefore, drycleaners are classified as a higher risk activity. Table 4-6 provides the groupings for the various screened source/activities.

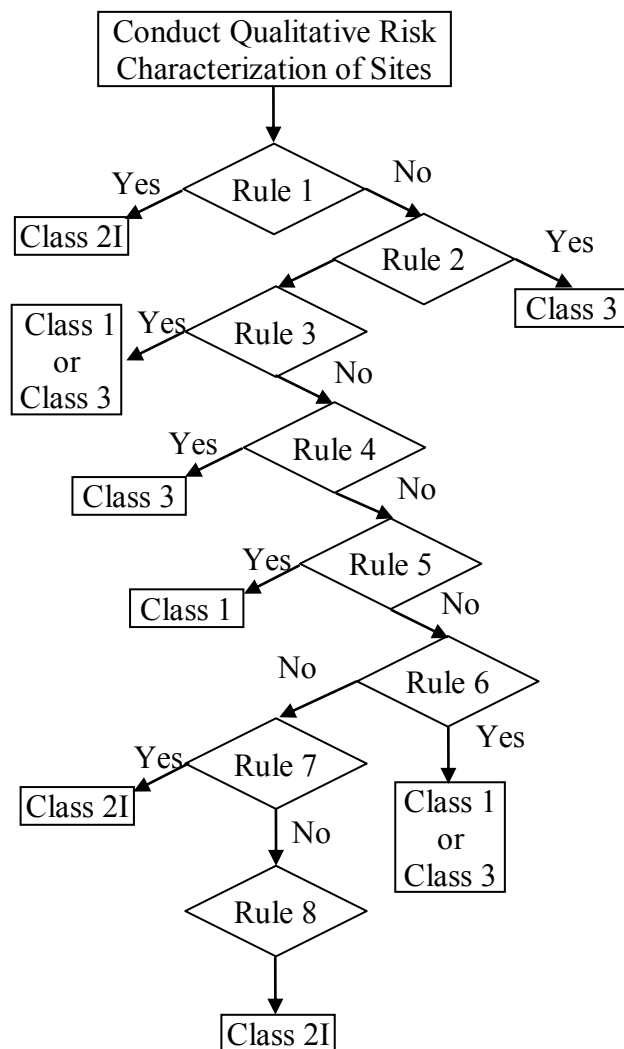
Due to the vast number of combinations possible with the above criteria the rules must be carefully constructed so that when the precise conditions specified are met, the appropriate conclusion is made (Abraham 2005). The entire process should be logical, transparent and make full use of the information available. To facilitate the process, a decision tree structure is recommended to clearly visualize the linguistic if-then rules (Zio et al. 2008). A decision tree functions in a step-wise manner, wherein each node contains

**Table 4-6: Risk Classification of Potentially Contaminating Sources / Activities**

| <b>Risk Level</b> | <b>Designation</b>       | <b>Source/Activity Category</b>                |
|-------------------|--------------------------|--|
| <b>High</b>       | <b>PCA1</b>              | Petroleum Handling Systems                     |
|                   |                          | Dry Cleaners                                   |
|                   |                          | Railway Operations                             |
|                   |                          | Miscellaneous 1                                |
|                   | <b>TANK 1*</b>           | Underground and/or Unknown Storage Tanks (UST) |
|                   | Foreign Utility Well     |  |
| <b>Medium</b>     | <b>PCA2</b>              | Auto Body Shops & Junkyards                    |
|                   |                          | Road Operations                                |
|                   |                          | Animal Processing & Fertilizer Production      |
|                   |                          | Miscellaneous 2                                |
|                   | <b>TANK2</b>             | Above ground Storage Tanks (AST)               |
|                   | Foreign Utility Pipeline |  |

\* UST + AST = TANK 1

a rule that acts as a test, with the result leading either to a final decision or to another node, rule and further testing. The decision tree and associated rules developed for sorting and classifying the screened sites is provided in Figure 4—1 and Table 4-7.



**Figure 4—1: Decision Tree**

**Table 4-7: Rule Based Decision System**

|                |   |
|----------------|---|
| <i>Rule 1:</i> | IF the area is < 0.05 acres (202m <sup>2</sup> ) then <u>Class 2I</u>   |
| <i>Rule 2:</i> | IF there is an Environmental Report for the site THEN <u>Class 3</u>  |
| <i>Rule 3:</i> | IF there is a source (PCA1 or PCA2, Tank 1 or Tank 2, Foreign Utility Well) on-site (and no reports on-site – Rule 2) THEN <u>Class 1</u> , EXCEPT IF the <u>only</u> source on-site is a Foreign Utility Pipeline, THEN <u>Class 3</u> |
| <i>Rule 4</i>  | IF there are environmental reports off-site/within 100m (and no sources on site – Rule 3) THEN <u>Class 3</u>   |
| <i>Rule 5:</i> | IF there are no environmental reports within 100m and there are high risk PCA's (PCA1 or Tank1 or a Foreign Utility Well) within 100m THEN <u>Class 1</u>   |
| <i>Rule 6:</i> | IF there are no environmental reports within 100m and there are medium risk PCA's (PCA2 or Tank 2) within 25m THEN <u>Class 1</u> EXCEPT IF the only medium risk PCA is a Foreign Utility Pipeline THEN <u>Class 3</u> .                |
| <i>Rule 7:</i> | IF there are no environmental reports within 100m and there are either no sources on-site or within 100m or there are only medium risk PCA's greater than 25m from the site THEN <u>Class 2I</u>  |
| <i>Rule 8</i>  | IF there are no environmental reports within 100m and no source of contamination either on-site or within 100m (i.e. none of the able rules apply) THEN <u>Class 2I</u>   |
| Class 1:       | action required - Phase I ESA recommended   |
| Class 2:       | No Further action required  |
| Class 3:       | Consult environmental reports available and reclassify site as Class 1 or Class 2I  |

#### 4.4 SCORING SYSTEM

After data collection, initial screening, and site classification is completed, a scoring system is used to rank the Class 1 and Class 3 sites; Class 2 sites are not included in the scoring as no potential environmental concerns are identified with these properties. The intent of the scoring system is to: provide a consistent, objective means for assessing the *relative* potential risk posed by a contaminated site; provide *relative* site rankings that would sufficiently distinguish between the potential risks posed by the sites; and provide a model that would require simple documentation, be scientifically defensible, and easy to use. The site rankings obtained are not to be construed as equivalent to risk assessment results but rather an objective comparison of sites based on *relative risk*, e.g. Site A poses higher risks than Site B (Robb 1990).

One of the ranking systems available in Canada is the National Classification System for Contaminated Sites (NCSCS). It was developed for and released by the Canadian Council of Ministers of the Environment (CCME) in response to the need for a scientifically defensible means of evaluating contaminated sites. The NCSCS is a management tool that functions to facilitate prioritization of actions by comparing the current and/or potential impact of anthropogenic substances on human health and the environment. It evaluates sites using an additive numerical methodology that assigns scores to site factors that are grouped under one of three equally significant and weighted categories: contaminant characteristics (33 points), migration potential (33 points) and exposure (34 points). The closer the final score is to the maximum 100 points, the greater the urgency for action (CCME 1992; 2008). The main disadvantage to directly applying this methodology as the scoring system is that the NCSCS recommends the completion of some form of formal environmental investigation prior to its application to assure data sufficiency.

As the purpose of the scoring system is to provide the municipality's environmental decision makers with a consistent framework to organize and compare information on potentially contaminated sites so as to prioritize the sites *requiring* Phase 1 ESA's, the NCSCS is not directly applicable at this stage primarily due to the discrepancy between the amount/type of

data required and the data available. However, the NCSCS framework is used as a basis to construct the scoring system.

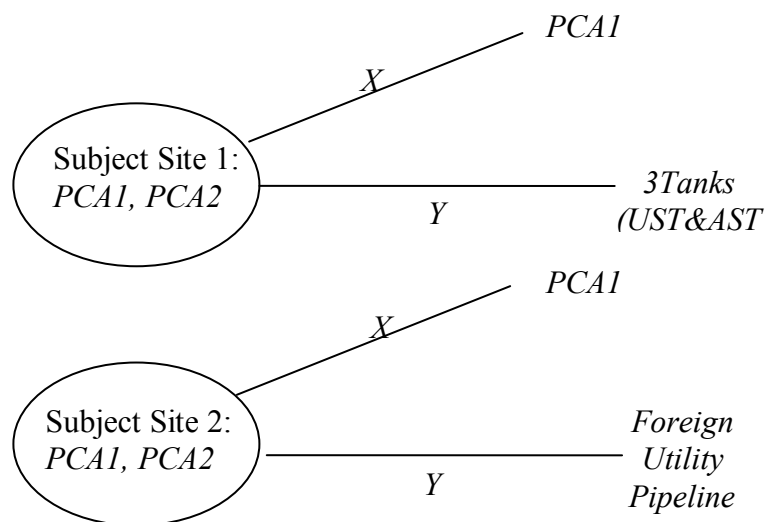
The site score developed for the Level 1 methodology is a multiplicative and additive algorithm that combines values from three weighted categories (Source, Receptor and Pathway) resulting in a numerical value between 1 and 100. The scoring system utilizes data that is readily available and incorporates as much information regarding the condition of the site as possible. Examination of the site factors chosen by the NCSCS revealed that the information available to municipalities is primarily within the contaminant characteristic category, followed by exposure and migration potential. Therefore, a small deviation from the NCSCS category weighting was adopted; Source (38 points), Pathway (30 points) and Receptor (32 points), with point allocation reflecting the amount of data available.

A series of formulae were developed for the scoring system incorporating comparisons of site:

- geology
- hydrology
- land use
- onsite sources
- sources within a designated buffer region of the subject site
- pathways for contamination, and
- receptors

Each formula includes all onsite and offsite conditions. The reasoning for this is best explained through the use of an example. Consider two sites, Subject Site 1 and Subject Site 2 (Figure 4—2). Subject Site 1 contains a high and a medium risk PCA onsite, and high risk PCA's at distances X and Y. Subject Site 2 also contains a high and medium risk PCA onsite, but only a high risk PCA at distance X and a medium risk Foreign Utility Pipeline at a distance Y. (Distances X and Y are the same for both sites with  $X < Y$  and both are within the designated buffer zone of 100m from the subject sites). If only the most hazardous activity/source onsite and the closest most hazardous activity/source offsite were considered these sites would be equivalent (both have two high risk activities; one PCA1 onsite and one

offsite). However, as there are more high risk activities/sources (PCA1's, UST's) associated with Site 1 it should be ranked higher.



**Figure 4—2: Sample Site Comparison**

An ideal score assignment should represent the exact situation observed at the site and transmit it to the decision makers without loss of information. However, when dealing with data that includes both numerical and linguistic input in numerous possible combinations this can be difficult. To facilitate the process, linguistic expressions such as high, medium and low risk are assigned to describe the various linguistic inputs (PCA's and sources, property/land use designations, water body category types, etc.) and then transformed into numeric values that can be used to produce a score that will ultimately rank the sites. Transformation into numeric values is achieved by assigning ranges of values to represent a specific linguistic expression. To represent the levels of perceived risk a range of values between 0.0 and 1.0, in increments of 0.1 is selected (Table 4-8).

**Table 4-8: Weight Definition**

| <b>RISK LEVEL OF CONCERN</b> | <b>VALUE RANGE</b>    | <b>DEFAULT VALUE</b> |
|------------------------------|-----------------------|----------------------|
| <b>Low</b>                   | $0.0 \leq x \leq 0.4$ | 0.4                  |
| <b>Medium</b>                | $0.4 < x \leq 0.6$    | 0.6                  |
| <b>High</b>                  | $0.6 < x \leq 1.0$    | 1.0                  |

These values function as a scalar that when applied in the scoring scheme will reduce the contribution of lower risk activities and lower risk designated property/land uses. The default value chosen to represent each risk level was the maximum listed in the category. This value is subject to change at the user's discretion. It is recommended that once a value is selected it remain unchanged for the duration of the assessment as it will alter final score value and, hence, the ranking.

Two major components identified in the screening process that will affect the scores are property and land use designations. The term "low", "medium" and "high" is applied to the various generalized land/property use designations employed by the municipality to indicate risk levels. Depending on whether the subject site contains a potential *source* of contamination or is a *receptor* for a potential source of contamination located within a designated buffer region surrounding the subject site, the risk term may vary. Selection of the risk term is both intuitive and dependent upon the experience of the participating investigators. The finalized rankings for the designations used by The City of Calgary are presented in Table 4-9 and Table 4-10.

**Table 4-9: Property Use Rankings**

| <b>Generalized Use</b>   |             | <b>SOURCE Ranking</b> | <b>RECEPTOR Ranking</b> |
|--------------------------|-------------|-----------------------|-------------------------|
| <b>Designation</b>       | <b>Code</b> |                       |                         |
| Agricultural             | AGR         | Low                   | Low                     |
| Commercial               | COM         | High                  | Medium                  |
| Environmental Reserve    | ER          | Low                   | Low                     |
| Industrial               | IND         | High                  | Lowest of the Low       |
| Institutional            | INST        | Medium                | High                    |
| Linear Property          | LP          | Low                   | Low                     |
| Multi-residential        | MRES        | Low                   | High                    |
| Municipal Reserve        | MR          | Low                   | Low                     |
| Municipal School Reserve | MSR         | Low                   | Low                     |
| Recreational             | REC         | Medium                | Low                     |
| Residential              | RES         | Low                   | High                    |
| Transportation           | TRANS       | Medium                | Low                     |

**Table 4-10: Land Use Rankings**

| <b>Generalized Use Designation</b>            | <b>SOURCE Ranking</b> | <b>RECEPTOR Ranking</b> |
|---|-----------------------|-------------------------|
| Low Density Residential                       | Low                   | High                    |
| Medium/High Density Residential               | Low                   | High                    |
| Commercial                                    | High                  | Medium                  |
| Industrial                                    | High                  | Low                     |
| Agricultural                                  | Low                   | Low                     |
| Direct Control                                | Medium                | High                    |
| Public Park, School and Recreation/Open Space | Medium                | Medium                  |
| Public Service                                | Medium                | Medium                  |
| University Research                           | Low                   | Medium                  |
| Urban Reserve                                 | Low                   | Low                     |



#### 4.4.1 *Preference Factors*

During the data collection process, as much reasonable data identifying as many onsite and offsite activities/sources is recommended to provide an accurate representation of the conditions both on and surrounding the site. This intrinsically results in more data being collected offsite than onsite as there is a minimum four (4) adjoining properties (Adj) and four (4) possible additional sites (Prox) in close proximity for every subject site (Figure 4—3).

|                                |                          |                                |
|--------------------------------|--------------------------|--------------------------------|
| North-West<br>Site<br>(Prox 4) | North<br>Site<br>(Adj 1) | North-East<br>Site<br>(Prox 1) |
| West<br>Site<br>(Adj 4)        | Subject<br>Site          | East<br>Site<br>(Adj 2)        |
| South-West<br>Site<br>(Prox 3) | South<br>Site<br>(Adj 3) | South-East<br>Site<br>(Prox 2) |

**Figure 4—3: Site Designations**

This uneven representation of data in the database requires correction to shift the emphasis back to the subject site. Thus, onsite and offsite preference factors are introduced with the value selected at the discretion of the user. Both onsite and offsite preference ranges vary from 0.50 to 0.95, with their sum totalling 1.0. Default values of were set at 0.7 and 0.3 for onsite and offsite preference factors, respectively. Again, it is recommended that once the user has selected these factors they not be changed as it will alter the ranking.

#### 4.4.2 *Land Use Factor Evaluation*

In order to evaluate the overall score for a site, one of the main contributing factors are property and land use designations. Land use designations are reflective of the zoning, whereas property and sub-property uses are reflective of the actual activities occurring on

the site. For sites that have multiple land, property and/or sub-property uses each is recorded in a separate database field, without any indication of priority.

While property use and zoning designations for a given site may differ (i.e. commercial zoning and commercial/residential property use as in the case of condominium developments) both of these types of designations can have an impact on the sites status as a source of contamination or a receptor of offsite contamination sources. In order to capture the information available two *Land Use Factors* are developed: (1) Land Use Source Factor, to represent conditions where the subject site contains a potential contaminating activity and behaves as a source, and (2) Land Use Receptor Factor when the subject site is a potential receptor of an offsite source/activity. The factors utilize the weights defined in Table 4-8 for the source and receptor rankings associated with each classification identified in Table 4-9 and Table 4-10.

#### **Equation 4–1: Land Use Source Factor (LUSF)**

$$LUSF = 0.5 \times Weight_{Property\ Use\ Source} + 0.5 \times Weight_{Land\ Use\ Source}$$

#### **Equation 4–2: Land Use Receptor Factor (LURF)**

$$LURF = 0.5 \times Weight_{Property\ Use\ Receptor} + 0.5 \times Weight_{Land\ Use\ Receptor}$$

While the contribution of the property and land use weights are considered equal (0.5) in the above equations, the final value is not to be construed as an average of the two weights. The contributions of each can be changed prior to entering the scoring process but their sum should not exceed 1.0 (i.e. 0.6 & 0.4; 0.3 & 0.7) and the same weightings should be employed in both calculations. As multiple non-prioritized property use and land use designations are allotted for each site, and each use has an associated risk ranking and weight assignment, the highest source and receptor weight assignment for the subject site is determined. It is these maximum property and land use source/receptor weights that are used in the aforementioned formulae.

#### 4.4.3 Source Score Evaluation

The source score is represented by a Contaminant Level of Hazard.

##### Equation 4–3 : Source Score (Max = 38 points)

$$Source = Contaminant\ Level\ of\ Hazard$$

It accounts for:

- the number and type of PCA's onsite
- the number and type of PCA's offsite (within a designated buffer region surrounding the subject site)
- associated PCA risk factor assignments and weights (High, Medium Low),
- contaminant distance to site,
- the total number of contaminant sources identified with the site (onsite & offsite), and
- the *maximum* total number of contaminant sources identified (onsite & offsite) of *all* sites under assessment
- onsite and offsite data disparity

Since a disparity can exist in number of fields identified for onsite and offsite potential activities/sources of contamination, separate calculations are performed for onsite and offsite sources components and the results proportionally combined through the use of the preference factors defined in Section 4.4.1 to produce a final source score. The general form for evaluating the Contaminant Level of Hazard is:

##### Equation 4–4: Contaminant Level of Hazard (CLH)

$$CLH = PrefOn \times SourceOn + PrefOff \times SourceOff$$

where,

PrefOn = onsite preference factor

PrefOff = offsite preference factor

SourceOn = onsite source parameter

SourceOff = offsite source parameter

The *SourceOn* and *SourceOff* parameters are each comprised of two components: one that focuses specifically on the potentially contaminating sources and the other on total contaminant quantity. The first component is allocated the majority of the source score points (22 out of 38) as it is the type of source that can significantly impact the condition of the site and there can be several types associated with the site. The second component, defined as a Quantity Factor (QF), is a comparative representation of the quantity of sources on the site with the maximum quantity of all the sites under investigation (Equation 4–5), and is assigned the remaining 16 points.

**Equation 4–5: Quantity Factor, QF**

$$QF = \frac{\# \text{ site specific sources}}{\text{maximum } \# \text{ site specific sources in dataset}}$$

4.4.3.1 Onsite Source Parameter, *SourceOn*

The onsite parameter of the source score is evaluated with the following equation:

**Equation 4–6: Onsite Source Parameter, *SourceOn***

$$SourceOn = 22 \times \left[ \frac{\left[ \frac{\sum PCA1 \times Risk + \sum PCA2 \times Risk + Tank1 \times Risk + Tank2 \times Risk + FUWell \times Risk + FUPipe \times Risk}{MAX_{numerator}} \right] \times LUSF}{MAX_{numerator}} \right] + 16 \times QF$$

where,

$\Sigma PCA1$  = Total # high risk potentially contaminating activity (Table 4-6)

$\Sigma PCA2$  = Total # medium risk potentially contaminating activity (Table 4-6)

Tank1 = # high risk tanks (underground storage or unknown tanks)

Tank2 = # medium risk tank (above ground storage tank)

FUWell = Foreign Utility Well

FUPipe = Foreign Utility Pipeline

Risk = Level of Concern value for associated source or activity (Table 4-8)

LUSF = Land Use Source Factor (Equation 4–1)

$MAX_{NUM}$  = Maximum numerator value evaluated for dataset

QF = Quantity Factor (Equation 4–5)

The first portion of the *SourceOn* parameter combines the total number of each type of onsite activity/source with their respective risk weights and prorates the resulting summation with the Land Use Source Factor. The Land Use Source Factor was selected since the subject site *contains* the potential sources of contamination. The summation of the PCA portions in the equation is used to incorporate all of the PCA's screened for the subject site and any combination of high and medium risk activities identified; one (1) PCA1 + three (3) PCA2 or, two (2) PCA1 and one (1) PCA2 or, four (4) PCA1 or, one (1) PCA2, etc. The resulting numerator for the subject site is then normalized against the maximum value of all the sites under evaluation providing a comparative assessment of the type of onsite activities.

#### 4.4.3.2 Offsite Source Parameter, *SourceOff*

The *SourceOff* parameter of the Contaminant Level of Hazard equation is computed in a similar manner as above, but differs in that the distance of the offsite source or activity from the edge of the subject site is also incorporated. Distances to the subject site are prorated for each source. The prorated/normalized value is a proportional representation of the location of the source within a buffer zone surrounding the site and is termed *normalized distance, ND*.

#### **Equation 4–7: Normalized Distance, *ND***

$$ND = 1 - \frac{\text{Source Distance}(m)}{\text{Buffer Zone Distance}(m)}$$

For a buffer zone of 100m, sources located at the boundary of the site have a distance of zero (0) meters resulting in a  $ND = 1$  whereas those located at the outer edge of the buffer zone have a  $ND = 0$ .

When assessing the PCA contributions a PCA quantity number parameter is not required in the equation as it is intrinsically equal to one (1) since each PCA source is associated with a distinct distance and, as such, must be managed as a separate entity in the equation as opposed to combining the similar source types together as seen in the onsite

component. For the offsite tanks a summation parameter is included as one distance is provided for all tanks identified, and the quantities vary. The offsite component equation is represented as:

**Equation 4–8: Offsite Source Component, *SourceOff***

$$SourceOff = 22 \times \frac{\left[ \sum_{j=1}^n (Risk_{PCAj} \times ND_{PCAj}) + \sum_{m=1}^k (Tank1 \times Risk_{Tank1m} \times ND_{Tank1m}) + \sum_{p=1}^r (Tank2 \times Risk_{Tank2m} \times ND_{Tank2m}) + \sum Risk_{FUTIL} \times ND_{FUTIL} \right]}{MAX_{numerator}} + 16 QF$$

where,

- j = # offsite PCA parcel entries in the database
- m,p = # offsite tank parcel entries in the database
- n, k, r = maximum number of respective entries in database
- PCA<sub>j</sub> = j<sup>th</sup> PCA entry in the database
- Tank1 = #high risk tanks (underground storage or unknown tanks)
- Tank2 = #medium risk tank (above ground storage tank)
- Risk = Level of Concern weighting for associated source/activity (Table 4-8)
- FUTIL = Foreign Utility (well or pipeline)
- ND = Normalized Distance for associated source/activity (Equation 4–7)
- QF = Quantity Factor

#### **4.4.4 Receptor Score Evaluation**

In risk assessments, receptors are generally identified as any living beings or resources that have the potential to be exposed to and affected by anthropogenic contaminants released into the environment (CCME 1992). Since Level 1 of the model framework involves the preliminary site screening in order to provide a basic classification and scoring of a suspected contaminated site, and the most readily identifiable receptors are localized water bodies, the receptor score is based on the hydrology associated with the site. Site screening identified several types of water bodies present on, bordering and within a designated buffer zone of the subject sites (Table 4-4) so, to facilitate handling

of the various water body types, a classification system was developed that places water bodies and water well types into four main categories: potable, agricultural/recreational, ecological and “other” (Table 4-11).

**Table 4-11: Water Body Classification**

| TYPE                  | CATEGORY  |
|-----------------------|---|
| Creek                 | Potable   |
| Drainage Ditch        | Ecological  |
| Irrigation Canal      | Agricultural/Recreational                                     |
| Lake                  | Agricultural/Recreational                                     |
| Undefined             | Other   |
| Reservoir             | Potable   |
| River                 | Potable   |
| Storm outfall Channel | Ecological  |
| Storm Pond            | Ecological  |
| Water Well            | Potable(Domestic), Agricultural, Industrial/Other, Underfined |
| Wetland               | Ecological  |

Each of these categories are assigned a perceived risk level of concern (Table 4-12) based on professional judgment, and utilizing the risk weight values defined previously in Table 4-8, each water body category is associated with a default risk level of concern.

**Table 4-12: Water Body Ranking**

| TYPE         | LEVEL OF CONCERN   |
|--------------|--------------------|
| Potable      | High               |
| Agricultural | Lowest of the High |
| Ecological   | Lowest of Medium   |
| Other        | Low                |

In addition to this, it is noted that the Water Well type classification is further divided into four sub-categories. These subcategories are assigned the same risk weight as their

similarly named main categories. These weight values selected can be changed at the time of analysis. However, it is recommended that once selected they remain unchanged through the duration of the assessment otherwise it will alter the ranking.

The onsite and offsite water body data recorded in the database is not consistent. Onsite water body screening includes:

- the identification of the largest water body(type) only,
- the present and type of water wells, and
- the total number of water bodies & water wells.

Whereas, offsite screening accounted for:

- the total number of water bodies within a designated buffer region
- the total number in each category/classification, and
- the shortest distance to the subject site for each category

The disparity in screening removed in the receptor score by incorporating an onsite and offsite component in the equation, similar to the Contaminant Level of Hazard calculation. The general form of the equation for evaluating the receptor score is:

**Equation 4–9: Receptor Score (Max = 32 Points)**

$$Receptor\ Score = 16 \times [((PrefOn \times RecOn) + (PrefOff \times RecOff)) + LURF]$$

where,

|         |   |   |
|---------|---|---|
| PrefOn  | = | onsite preference factor                |
| PrefOff | = | offsite preference factor               |
| RecOn   | = | onsite receptor parameter               |
| RecOff  | = | offsite receptor parameter              |
| LURF    | = | Land Use Receptor Factor (Equation 4–2) |

The onsite and offsite receptor components have the potential (when combined) to equate to a value of 1.0, as does the LURF. Therefore, a scalar value of 16 is applied to the final



sum to obtain a maximum receptor score of 32 points. The LURF was selected for use in the receptor evaluation since the property/site under assessment is essentially the receptor of potential contaminant migration, regardless of whether the source of contamination is onsite or within the buffer zone surrounding the site.

As both onsite and offsite screened data include the total number of receptors present, a generalized quantity factor similar to Equation 4–5 is used for the water bodies identified: Water Body Factor, WBF.

**Equation 4–10: Water Body Factor, WBF**

$$WBF = \frac{\# \text{ site specific water body/wells}}{\text{maximum \# site specific water body/wells in data set}}$$

4.4.4.1 Onsite Receptor Component, *RecOn*

Based on the hydrology information available, the onsite component of the receptor score is calculated as:

**Equation 4–11: Onsite Receptor Component, *RecOn***

$$RecOn = \frac{WBW_{ON} \times WBF_{ON}}{Max_{NUM}}$$

where,

- $WBW_{ON}$  = Maximum of water body/well category weight
- $WBF_{ON}$  = Onsite Water Body Factor (Equation 4–10)
- $Max_{NUM}$  = Maximum numerator value evaluated for dataset

The  $WBW_{ON}$  parameter in the above equation represents the maximum weight associated with the classification of *either* the largest water body identified *or* the water well

identified. The maximum is selected to be protective of all water forms, regardless of size.

#### 4.4.4.2 Offsite Receptor Component, *RecOff*

The offsite component of the receptor score is calculated similarly to the onsite component but incorporates the prorated distance, ND, of the closest water body or water well to the subject site.

#### Equation 4–12: Offsite Receptor Component, *RecOff*

$$RecOff = \frac{(\sum_{i=1}^4 WBW_i \times WBF_i \times ND_i)}{Max_{NUM}}$$

where,

$i$  = Water body/well category (potable, agricultural/recreational, ecological, other)

$WBW_i$  = Water body/well category weight

$WBF_i$  = Category specific water body factory (Equation 4–10)

$ND_i$  = Normalized Distance

$Max_{NUM}$  = Maximum numerator value evaluated for dataset

Application of the WBF to the offsite data differs from that on the onsite application since, in addition to a combined total number of receptors being identified, the offsite screening also provides a sub-total for each of the water type categories (potable, agricultural/recreational, ecological and other). A WBF is evaluated for each category and applied to the category specific quantity and normalized distance. Thus, the offsite component is a culmination of contributions from each water body category identified within the buffer region surrounding the site.

#### ***4.4.5 Pathways Score Evaluation***

Pathways are the routes by which contaminants *travel* from their source to a potential receptor. For the purpose of Level 1 screening and classification of potentially contaminated sites, the pathway score is developed from the following contributing features:

- surficial geological material (media),
- contaminant migration potential and,
- direct physical contact potential

The first two features fall under the category of contaminant transport. Contaminant transport is dependent on the media it is exposed to and the physical nature of the chemical itself. Properties of these two elements are combined to form the first component of the pathways score.

**MEDIA:** An estimate of the potential for contaminant migration can be attained through examination of the permeability and/or hydraulic conductivity of the media. Permeability is measure of the ability of a soil to transmit liquids and is a function of pore size (Schnoor 1996). As grain size increases, pore size and permeability also increase. As grain size decreases, resistance to flow increases and permeability decreases. The greater the permeability, the faster the fluid will reach groundwater. Hydraulic conductivity describes the rate of flow per unit time per unit cross-sectional area and is dependent upon the intrinsic permeability of the media. Since permeability and hydraulic conductivity are related, in the absence of specific field/laboratory permeability testing the intrinsic hydraulic conductivity for the media is used in this model.

While there are several types of soil classifications, the screening process included only two specific categories, gravel and sand, with the remaining soil types being combined into the “other” category. Literature values for intrinsic hydraulic conductivity are listed in Table 4-13. The range provided for the “sand” category includes silty, fine and well sorted sands. The “other” category includes those grains smaller than silty sand; till, clayey sands, sandy

silts, silt, and clay (Fetter 2001). For each range, the largest hydraulic conductivity value is selected to represent the worst-case scenario.

**Table 4-13: Intrinsic Hydraulic Conductivity**

| SOIL CATEGORY | HYDRAULIC CONDUCTIVITY (CM/S) |                |
|---------------|-------------------------------|----------------|
|               | RANGE                         | VALUE SELECTED |
| Gravel        | $10^{-2} - 1$                 | 1              |
| Sand          | $10^{-5} - 10^{-1}$           | 0.1            |
| Other         | $\leq 10^{-5}$                | 0.00001        |

A unitless parameter representing the hydraulic conductivity is used for the purposes of evaluating the Pathways Score. The Geological Material Factor, GMF, is a ratio of the hydraulic conductivity of the soil at the site to the largest hydraulic conductivity of all the soil categories, namely gravel.

**Equation 4-13: Geological Material Factor, GMF**

$$GMF = \frac{HCF_i}{HCF_{gravel}}$$

where,

GMF = Geological Material Factor(unitless)

$HCF_i$  = Hydraulic Conductivity of material at site (cm/s)

$HCF_{gravel}$  = Hydraulic Conductivity of gravel (cm/s)

**CONTAMINANT MIGRATION POTENTIAL:** Contaminants are either naturally occurring substances that are present in elevated quantities compared to background concentrations, or non-naturally occurring (anthropogenic) substances. The anthropogenic compounds tend to be more prevalent when working with contaminated sites and it is their chemical nature that dictates the risk posed by their presence. Two basic chemical specific characteristics that are used to indicate migration potential are persistence and mobility.

Persistence is represented by the time a chemical takes to degrade to half its concentration, half life ( $T_{1/2}$ ). Environment Canada has provided a standardized categorization of half-life criteria based on media to be used in risk assessments (Environment Canada 2006a). For soil and water media, the half-life criteria is  $T_{1/2} \geq 182$  days (4368 hours) indicating that any compound with a half-life meeting this criterion is considered to be persistent; the greater the value, the more persistent the compound.

Mobility of a compound refers to the degree to which it moves from soil to groundwater. The most commonly used chemical-specific parameter for indicating this movement is the soil organic carbon partition coefficient, Koc. This parameter compares the concentration of a chemical in organic media (soil) to its concentration in water. If the concentration in soil is greater than in water (high Koc), the compound is considered to be preferentially bound to the soil and less likely to move. If, however, the opposite is true, the compound preferentially moves from the soil to water; higher mobility. According to the classification scheme provided by the FAO United Nations, compounds with a Log Koc between 1 and 2 are considered mobile, and those with a Log Koc less than 1 are considered highly mobile (FAO United Nations 2000).

In the absence of analytical test results, identification of contaminants is restricted to assumptions based on the potentially contaminating activities and/or sources identified with a specific site. Depending on the nature of the activity, specific classes of compounds can be identified and indicator compounds can be predicted.

For example, the activities classified under the Petroleum Handling Systems category in Table 4-3 (i.e. gas stations, auto/truck repair facilities, shop/garage; petroleum bulk storage/bulk distribution facilities; etc.) are all activities that primarily work with/handle petroleum based products and commonly are associated with the identification of benzene, toluene, ethyl benzene and xylene (BTEX) in the environment. To determine the indicator compound for this category, the persistence and mobility characteristics of the most common compounds are examined and compared (Table 4-14).

**Table 4-14: Common Contaminants of Petroleum Handling Systems**

| TYPICAL<br>CHEMICALS  | PERSISTENCE                            |                                   | MOBILITY |   |
|---|--|-----------------------------------|----------|---|
|   | HALF LIFE,<br>T <sub>1/2</sub> (HOURS) | HALF LIFE<br>RATIO <sup>1,3</sup> | LOG KOC  | MOBILITY<br>CLASSIFICATION <sup>2</sup> |
| Benzene   | 8760                                   | 2.01                              | 1.8482   | mobile                                  |
| Toluene   | 672                                    | n/a                               | 2.7769   | moderately mobile                       |
| Ethylbenzene  | 5472                                   | 1.25                              | 2.7335   | moderately mobile                       |
| Xylene  | 8640                                   | 1.98                              | 2.7074   | moderately mobile                       |
| <sup>1</sup> (Environment Canada 2006a)<br><sup>2</sup> (FAO United Nations 2000)<br><sup>3</sup> Half Life Ratio = T <sub>1/2(chemical)</sub> / T <sub>1/2(soil , water)</sub> = T <sub>1/2(chemical)</sub> / 4368 hours |  |                                   |          |   |

According to Table 4-14, benzene exhibits the greatest half-life and mobility values and thus is considered to be the indicator compound for the Petroleum Handlings Systems activity category.

Another example of an indicator compound is for the Dry Cleaning Sites activity category. The most commonly used chemicals in this industry were trichloroethylene (TCE) and PCE (tetrachloroethylene) until their hazardous nature was identified and more environmentally friendly alternative were developed. These compounds, hazardous in their own right, degrade in the environment and produce daughter products that are considered to be even more hazardous, namely dichloroethylene (DCE) and vinyl chloride(VC). This is evident through the comparison of their persistence and mobility values (Table 4-15). The most persistent and most mobile of these chemicals is vinyl chloride and thus is selected as the indicator compound for the Dry Cleaning Sites category.

**Table 4-15: Common Contaminants of Dry Cleaning Sites**

| TYPICAL CHEMICALS   | PERSISTENCE                            |                                      | MOBILITY      |   |
|---|--|--------------------------------------|---------------|---|
|   | HALF LIFE,<br>T <sub>1/2</sub> (HOURS) | HALF<br>LIFE<br>RATIO <sup>1,3</sup> | LOG<br>KOC    | MOBILITY<br>CLASSIFICATION <sup>2</sup> |
| Tetrachloroethene (PCE)   | 17280                                  | 3.96                                 | 2.9505        | moderately mobile                       |
| Trichloroethene (TCE)   | 39672                                  | 9.08                                 | 2.0999        | moderately mobile                       |
| Dichloroethene (DCE)  | <b>69000</b>                           | 15.80                                | 1.8135        | mobile                                  |
| Vinyl Chloride (VC)   | <b>69000</b>                           | 15.80                                | <b>1.4056</b> | <b>mobile</b>                           |
| <sup>1</sup> (Environment Canada 2006a)<br><sup>2</sup> (FAO United Nations 2000)<br><sup>3</sup> Half Life Ratio = T <sub>1/2</sub> (chemical) / T <sub>1/2</sub> (soil ,water) = T <sub>1/2</sub> (chemical) / 4368 hours |  |                                      |               |   |

The indicator chemicals for the two potentially contaminating activity categories shown above were easily identified since the chemical exhibited the highest value in each category of all the chemicals used in the comparisons. However, if the dataset for an activity category consisted of the BTEX compounds and DCE, for example, DCE would be identified as the most persistent and benzene the most mobile (albeit slightly) and the selection of the indicator chemical would not be as clear. Therefore, a standardized means of determining the indicator compound is required in the case where one chemical is the most persistent and another is the most mobile. To facilitate the process, a Maximum Travel Time Adjustment (MTTA) parameter is introduced to reflect the migration potential of the indicator chemicals associated with the activity categories identified. The MTTA is based on a combination of mobility and persistence scores for each chemical.

**Equation 4–14: Mean Travel Time Adjustment, MTTA**

$$MTTA = \frac{S_P + S_M}{2}$$

where,

S<sub>P</sub> = Persistence Score

$S_M$  = Mobility Score

In order to determine the persistence and mobility scores, the actual values must be transformed into a linguistic category such as low, medium and high and a weight score applied using Table 4-8. As Environment Canada provides only a “start” point where chemicals are considered to be persistent, it is difficult to categorize the degree of persistence when comparing chemicals so a half-life ratio is introduced to aid in the comparison. Although benzene has approximately twice the half-life as the criteria value, it cannot be classified as highly persistent based only on comparison with the other possible contaminants in its activity category. The linguistic classification of persistence (low, medium, high) must be based on a larger dataset. If the chemicals in Table 4-14 and Table 4-15 are considered together, the half-life ratios range from slightly greater than unity to approximately 16. If unity is taken to be equivalent to a medium classification of persistence and any half-life ratio greater than 10 be equivalent to a high persistence classification, a persistence score can be obtained for each chemical under evaluation. Using this as a basis, ethyl benzene with a 1.25 half-life ratio would be assigned a persistence score near the lower end of the medium range (i.e. 0.4); TCE with a 9.08 half-life ratio would be assigned a score near the upper end of the high range (i.e. 0.9), and DCE and VC with 15.80 half-life ratios be assigned the maximum value of 1.0. The persistence scores for the two activity categories examined are presented in Table 4-16.

The mobility classification provided by the FAO United Nations is, however, more defined and if the boundary between moderately mobile and mobile is set at the middle value of the medium weight range the corresponding mobility scores can be readily obtained (i.e. Log K<sub>oc</sub> = 2.0 is associated with a mobility score of 0.5). For example, ethyl benzene with a Log K<sub>oc</sub> closer to 3 is in the moderately mobile category and is assigned a mobility score of 0.3. Benzene’s value is slightly less than 2.0 and is considered close enough to the boundary to be assigned a mobility score of 0.5, but DCE, which is slightly less than benzene and further from the 2.0 value is assigned a slightly higher mobility score of 0.6. The closer the Log K<sub>oc</sub> is to 1.0, the higher the mobility score. The mobility scores for the two activity categories examined are presented in Table 4-16.



Once the persistence and mobility scores are assigned, an average is obtained and the maximum value of the chemicals examined for a given activity category is used as representative of that category. This value is known as the MTTA. (Table 4-16)

**Table 4-16: MTTA Sample Calculation**

| <b>Activity Category</b>   | <b>Chemical</b> | <b>Persistence Score, <math>S_p</math></b> | <b>Mobility Score, <math>S_p</math></b> | <b>Average Score</b> | <b>MTTA</b> |
|----------------------------|-----------------|--|---|----------------------|-------------|
| Petroleum Handling Systems | Benzene         | 0.5  | 0.5                                     | <b>0.50</b>          | <b>0.5</b>  |
|                            | Toluene         | 0.0  | 0.3                                     | 0.15                 |             |
|                            | Ethyl Benzene   | 0.4  | 0.3                                     | 0.35                 |             |
|                            | Xylene          | 0.4  | 0.5                                     | 0.45                 |             |
| Dry Cleaning Sites         | PCE             | 0.8  | 0.3                                     | 0.55                 | <b>1.0</b>  |
|                            | TCE             | 0.9  | 0.5                                     | 0.70                 |             |
|                            | DCE             | 1.0  | 0.6                                     | 0.80                 |             |
|                            | VC              | 1.0  | 0.9                                     | <b>0.95</b>          |             |

Using the aforementioned process, MTTA values were obtained for all the activity classifications identified in Table 4-3 and in cases where the categories encompassed activities with different characteristic contaminants (e.g. Misc1, Misc 2), separate MTTA values were evaluated for each activity of concern. These values are listed in Table 4-17 and Table 4-18.

Potentially contaminating activity screening allowed for the identification of the activity category and the specific activity of concern for each onsite and offsite entry, in decreasing order of risk. An activity code was also assigned to the highest risk activity identified to assure that the highest MTTA be used as representative of the site. In the case where no PCA's are recorded but either a Tank 1, Tank2, Foreign Utility Well or Pipeline are recorded onsite or within the buffer region, the MTTA is automatically assigned a value of 0.5. The activity codes are provided in Table 4-17 and Table 4-18.

**Table 4-17: MTTA for High Risk PCA's**

| <b>Activity Category</b>  | <b>Activity of Concern</b>  | <b>Activity Code</b> | <b>MTTA</b> |
|---------------------------|---|----------------------|-------------|
| Petroleum Handling System | Gas station   | GAS                  | 0.5         |
|                           | Auto/truck repair, shop/garage  | AUTO                 | 0.5         |
|                           | Petroleum bulk storage/bulk distribution facilities   | BULK                 | 0.5         |
|                           | Site containing petroleum storage tanks for fuelling equipment  | FUEL                 | 0.5         |
| Dry Cleaners              |   | DRY                  | 1.0         |
| Railway Operations        | Railway Operations; Rail yards (not including Railway tracks)   | RAIL                 | 0.5         |
| Misc. 1                   | Wood preserving or processing   | WOOD                 | 0.5         |
|                           | manufacturing or processing of plastics/Styrofoam, sulphur products, tires, rubber products, carpets, metals/metal products, paper/paper products, bricks, wire/wire rope | MFG                  | 0.4         |
|                           | Oilfield/pipeline/refinery operations   | OIL                  | 0.5         |
|                           | Chemical manufacturing, blending, processing or storage   | CHEM                 | 0.5         |
|                           | Storage or processing of hazardous waste  | HAZ                  | 0.5         |
|                           | Veneer, lacquer and/or paint operations   | PAINT                | 0.5         |
|                           | Land farming facility (for petroleum, drilling or other waste)  | LF                   | 0.4         |
|                           | Mine or Gravel Pit (for Petroleum Storage Tank impacts, uncontrolled fill and/or organic fill)  | PIT                  | 0.5         |

**Table 4-18: MTTA for Medium Risk PCA's**

| <b>Activity Category</b>                    | <b>Activity of Concern</b>                          | <b>Activity Code</b> | <b>MTTA</b> |
|---|---|----------------------|-------------|
| Auto Body Shops & Junkyards                 | Auto body shop or garage                            | BODY                 | 0.5         |
|   | Metal plating/finishing                             | METAL                | 1.0         |
|   | Auto wrecking/scrap metal                           | WRECK                | 1.0         |
|   | Machining   | MACH                 | 1.0         |
| Road Operations                             | Snow Storage/disposal                               | SNOW                 | 1.0         |
|   | Roads maintenance and salt storage yards            | ROAD                 | 1.0         |
| Animal Processing and Fertilizer Production | Slaughter house or other food processing            | WHACK                | 1.0         |
|   | Agricultural land with livestock operations         | AGRIC                | 1.0         |
|   | Tannery   | TANN                 | 1.0         |
|   | Fertilizer, herbicide and pesticide products        | FERT                 | 1.0         |
|   | Land application of waste sludge's                  | SLUDGE               | 1.0         |
| Misc. 2                                     | Battery Storage, maintenance, recycling or disposal | BATT                 | 1.0         |
|   | Electric equipment repair                           | ELEC                 | 0.5         |
|   | Asphalt; concrete, cement, gypsum or lime products  | ASPH                 | 0.5         |
|   | Coal facilities                                     | COAL                 | 0.4         |
|   | Photographic industry                               | PHOTO                | 1.0         |
|   | Explosives and firing ranges                        | EXPLO                | 0.5         |
|   | Armouries and other military facilities             | MILITARY             | 1.0         |
|   | Uncontrolled waste disposal and sewage treatment    | UDUMP                | 1.0         |
|   | Controlled waste disposal and sewage treatment      | WEDUMP               | 1.0         |
|   | Airports or aircraft maintenance facilities         | AIR                  | 0.9         |
|   | Railway tracks                                      | RAILT                | 1.0         |
|   | Hospitals, pharmaceutical or medical industry       | HOSP                 | 0.5         |
|   | Funeral services                                    | FUN                  | 0.5         |
|   | Distilleries or breweries                           | BEER                 | 0.5         |
|   | Incinerators or boilers/heat exchange industry      | HASH                 | 0.4         |
|   | Commercial refrigeration or air conditioning        | REFRIG               | 0.4         |
|   | Insulating material                                 | INS                  | 0.5         |
|   | Tar and roofing materials                           | TAR                  | 0.5         |
|   | Milling   | MILL                 | 0.5         |

**DIRECT CONTACT:** The final feature contributing to the Pathways Score is that of direct contact. Direct contact represents the *potential* for direct physical contact with contaminated soil. The only conditions where this can occur is when exposure to soil is not impeded by any form of “surface capping” such as asphalt or concrete paving. Of the property use designations provided, the categories where exposure for direct contact is most likely to occur (high perceived risk) are:

- environmental reserve
- institutional
- educational
- linear property
- residential
- multi-residential
- agricultural, or
- municipal reserve

All others are considered low risk areas due to the likelihood of large paved surfaces.

The Pathways Score is composed of two components: a transport component and a contact component. The transport component is a combination of the geological material and the MTTA, and thus is allotted a higher weighting in the score (20 of the 30 available points). The contact component is given the remaining points (10). Thus, the equation is:

**Equation 4–15: Pathways Score (MAX = 30 points)**

$$Pathway\ Score = 20 \times [GMF \times MTTA] + 10 \times DCF$$

where,

GMF = Geological Material Factor (unitless)

MTTA = Mean Travel Time Adjustment (unitless)

DCF = Direct Contact Factor (unitless; high risk = 1.0, low risk = 0.4)

#### 4.4.6 Final Score Evaluation

Once the source, pathway and receptor scores are evaluated for each site under assessment, the final score is obtained through simple summation:

**Equation 4–16: Final Site Score (MAX = 100 points)**

$$\text{Final Score} = \text{Source Score} + \text{Receptor Score} + \text{Pathway Score}$$

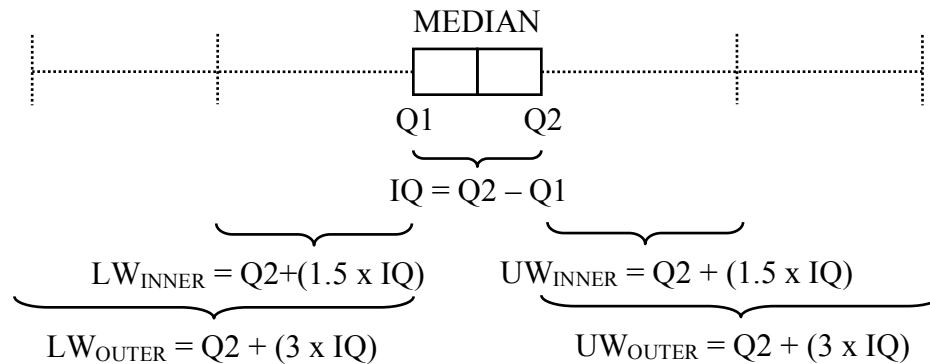
### 4.5 DATA HANDLING

During the screening process several numerical entries are recorded regarding quantity of tanks, PCA's and water bodies/wells onsite and within a specified buffer region as well as distances of sources/activities and receptor to the parcel under review. These entries can vary significantly depending of the location of the site and thus there is a potential for a value to “appear” to be inconsistent with others in a given dataset. This value(s) may be considered to be either ‘extreme’ or an outlier.

Several methods exist to facilitate the identification of outliers. Many of these require robust statistical analysis but one of the commonly used methods is the Box Plot. The Box Plot does not require data that is normally distributed because it depends on the median and not the mean of the data. A Box Plot is a graphical representation of the data wherein the median, lower (Q1) and upper (Q2) quartiles (25<sup>th</sup> and 75<sup>th</sup> percentiles, respectively) are identified to form a “box”, and the inter-quartile distance (IQ = Q2-Q1) is used to define the “whiskers”. An example of a typical box plot is shown in Figure 4—3.

The box contains 50% of the data and it is the “whiskers” that aid in identifying the outliers. Two sets of “whiskers” are defined:

- environmental reserve Outer whiskers: lower(LW<sub>OUTER</sub>) and upper(UW<sub>OUTER</sub>)
- municipal reserve Inner whiskers: lower(LW<sub>INNER</sub>) and upper(UW<sub>INNER</sub>)



**Figure 4—4: Box Plot**

Outer whiskers are used for identifying unusually high data beyond which only a small percentage of data exist. The inner whiskers provide a point for which a moderate number of data may exist beyond, ensuring all potential outliers are included. Once the whiskers are identified for a dataset the value closest to, but not exceeding the inner whisker is selected as the reference data point. All points beyond are considered suspect. The data points located between the inner and outer whiskers are classified as mild outliers, whereas those beyond the outer whiskers are considered to be highly suspect and classified as extreme outliers. (Benjamini 1988; Frigge et al. 1989)

While the advantage of using the Box Plot lies in its simplicity and its non-reliance on normally distributed data, the necessity of rearranging the data such that it is in ascending numerical order removes its applicability in this model. As there is a significant amount of data to be examined, the best course is to use the data without manipulation. Therefore, a statistically based alternative to identifying and defining outliers was selected that provided comparable results to the Box Plot methodology (Equation 4–17).

### Equation 4–17: Outlier Identification

$$Outlier = Mean + 2 \times StdDev$$

where,

Mean = Average of the dataset

$$\frac{\sum_{i=1}^N Data\ Value}{N}$$

StdDev = Standard Deviation

$$= \sqrt{\frac{\sum_{i=1}^N (Data\ Value - Mean)^2}{N-1}}$$

N = Number of entries in dataset

Outliers were identified based on a dataset that included only Class 1 and Class 3 sites as Class 2I sites required no further investigation. Data entered as “n/a” or “(blank)” or distances greater than the designated buffer region are not included in the outlier calculations. If a distance greater than the buffer region was recorded, both the distance and its associated source were removed from the working dataset (original database remained unchanged). Typical values for the Box Plot Method and the selected, statistically based, outlier methodology are provided for the Tank Data in Table 4-19 .

**Table 4-19: Outlier Methodology Comparison**

| Dataset  |        |                  | Box Plot Method     |                     | Statistical Based Method <sup>2</sup> |
|--|--------|------------------|---------------------|---------------------|---------------------------------------|
| Type   |        | Max <sup>1</sup> | Upper Inner Whisker | Upper Outer Whisker |                                       |
| Onsite Tanks   | #AST's | 6                | 7                   | 11                  | 7                                     |
|  | #UST's | 11               | 13                  | 20                  | 11                                    |
| Offsite Tanks  | Total  | 47               | 14                  | 20                  | 29                                    |
|  | #AST's | 13               | 13                  | 20                  | 18                                    |
|  | #UST's | 18               | 9                   | 14                  | 15                                    |
| <sup>1</sup> The maximum value listed is from Class 1 and Class 3 Sites <b><u>only</u></b><br><sup>2</sup> Equation 4–17 |        |                  |                     |                     |                                       |

Two (2) standard deviations beyond the mean were selected to ensure that the outlier reference value was as close as possible to the upper inner and outer whisker values obtained through the Box Plot Method. The results shown above are typical for the datasets examined. Any exceptions tend toward the conservative side including more data into the dataset and excluding less as outliers. Any data identified as an *outlier was not discarded*, rather it was considered to be equivalent to the closest real value to the outlier reference number. For example, in the case of total offsite tanks the outlier reference number is 29 and the closest number in the dataset is 27. Any numbers in the dataset greater than the ‘real’ number 27 (i.e. 34, 37, and 47) are considered outliers. These values are not discarded but rather they are considered to be equal to the closest ‘real’ data value (i.e. 27) in the calculations. The original database remains unaltered, the substitution occurs in the calculations only.

Outliers were identified for all numerical entries *including offsite distances*. The likelihood of an outlier existing in the distance datasets is small given that the distances are restricted a specific maximum (buffer region) and the outlier reference values are generally greater. However, if a set of data is encountered wherein the majority of distances are all smaller values (i.e. close to the subject site), the outlier reference value could theoretically be less than designated buffer region distance and thus needs to be detected and accounted for.



## 4.6 SENSITIVITY ANALYSIS

The Level 1 Model for the DSS was tested on a large size database (600+ sites). While there are many weights that can be altered by the user, a sensitivity analysis was performed using the preference factor weightings. Preference factor weightings are considered to have the greatest effect on the scores obtained for the sites as their primary function is to proportion the onsite and offsite source and receptor score components and correct the disparity in data collection (see 4.4.1).

The Level 1 Model was performed using onsite – offsite preference factor combinations of 50:50, 60:40, 70:30 (default), 80:20, and 90:10. The results of the sensitivity test for the top 51 sites are presented in Table 4-20. As the onsite preference weight shifts from 50% to 90%, the top three ranked sites remain in the same order and position whereas the other sites begin to move either upwards or downwards in rank position. The movement is dependent upon the contribution of offsite data to the overall score. The movement may be one or two positions, as seen with Site 373 and Site 375, or may be as much as then 25 positions observed with Site 604.

Examination of the parameters associated with Site 604 reveals that onsite sources were identified (no offsite sources). Therefore, by reducing the impact/contribution from offsite components in the evaluation of the source score, the impact of the onsite source increases causing the site to move upwards in rank.

In contrast to Site 604, Site 236 decreases in rank by 10 positions. Examination of the parameters associated with this site reveals that no onsite sources have been identified but several offsite sources were. The decrease in rank with an increase in on-site preference factor indicates that the offsite sources were driving the position and giving an overestimation of the potential risk associated with that site.

From this analysis, the 70:30 proportioning of onsite to offsite contributions to the overall site score appears to provide an appropriate balance for handling the disparity in data collection for *this set of data*.

Table 4-20: Level 1 Model Sensitivity Analysis (Preference Factor)

| Site Rank | Preference Factor<br>(Onsite : Offsite) |                |                |                |                |
|-----------|---|----------------|----------------|----------------|----------------|
|           | 50:50                                   | 60:40          | 70:30          | 80:20          | 90:10          |
| 1         | 331                                     | 331            | 331            | 331            | 331            |
| 2         | 353                                     | 353            | 353            | 353            | 353            |
| 3         | 354                                     | 354            | 354            | 354            | 354            |
| 4         | 181                                     | 324            | 324            | <del>408</del> | <del>408</del> |
| 5         | 324                                     | 181            | <del>408</del> | 324            | 373            |
| 6         | 182                                     | 182            | 182            | 373            | 324            |
| 7         | 186                                     | 373            | 373            | 182            | 182            |
| 8         | 373                                     | <del>408</del> | 181            | 11             | 11             |
| 9         | <del>375</del>                          | <del>375</del> | <del>375</del> | <del>375</del> | 234            |
| 10        | 146                                     | 186            | 166            | 166            | <del>375</del> |
| 11        | 166                                     | 166            | 11             | 181            | 166            |
| 12        | 185                                     | 185            | 186            | 234            | 359            |
| 13        | 572                                     | 11             | 185            | 359            | 54             |
| 14        | 11                                      | 146            | 234            | 54             | 588            |
| 15        | <del>408</del>                          | 427            | 427            | 427            | 427            |
| 16        | 427                                     | 234            | 359            | 185            | 181            |
| 17        | 624                                     | 359            | 54             | 186            | 185            |
| 18        | 234                                     | 54             | 146            | 588            | 480            |
| 19        | 12                                      | 572            | 588            | 480            | 477            |
| 20        | 359                                     | 624            | 624            | 477            | 186            |
| 21        | 54                                      | 12             | 477            | 624            | 479            |
| 22        | 313                                     | 477            | 12             | 479            | 461            |
| 23        | 477                                     | 504            | 480            | 461            | 244            |
| 24        | 504                                     | 480            | 504            | 12             | 241            |
| 25        | 632                                     | 588            | 632            | 244            | 603            |
| 26        | 226                                     | 632            | 479            | 241            | <del>604</del> |
| 27        | 189                                     | 226            | 226            | 504            | 605            |
| 28        | 480                                     | 313            | 461            | 632            | 606            |
| 29        | 597                                     | 479            | 572            | 603            | 607            |
| 30        | <b>236</b>                              | 461            | 244            | <del>604</del> | 608            |
| 31        | 30                                      | <b>236</b>     | 481            | 605            | 613            |
| 32        | 249                                     | 244            | <b>236</b>     | 606            | 614            |
| 33        | 588                                     | 481            | 241            | 607            | 624            |
| 34        | 214                                     | 249            | 249            | 608            | 481            |
| 35        | 479                                     | 189            | 247            | 613            | 391            |
| 36        | 481                                     | 247            | 603            | 614            | 12             |
| 37        | 461                                     | 237            | <del>604</del> | 226            | 504            |
| 38        | 596                                     | 246            | 605            | 481            | 632            |
| 39        | 247                                     | 241            | 606            | 146            | 226            |
| 40        | 244                                     | 597            | 607            | <b>236</b>     | <b>236</b>     |
| 41        | 237                                     | 391            | 608            | 391            | 249            |
| 42        | 246                                     | 30             | 613            | 249            | 247            |
| 43        | 15                                      | 603            | 614            | 247            | 237            |
| 44        | 187                                     | <del>604</del> | 237            | 237            | 246            |
| 45        | 188                                     | 605            | 391            | 246            | 184            |
| 46        | 391                                     | 606            | 246            | 184            | 482            |
| 47        | 241                                     | 607            | 313            | 482            | 74             |
| 48        | 184                                     | 608            | 184            | 74             | 164            |
| 49        | 625                                     | 613            | 482            | 164            | 245            |
| 50        | 603                                     | 614            | 74             | 572            | 73             |
| 51        | <del>604</del>                          | 184            | 164            | 245            | 379            |

#### 4.7 MODEL LIMITATIONS

The DSS developed for the Level 1 Model provides a viable methodology. However, due to the inherent nature of some of the data and assessment paradigms applied, assumptions were made that may contribute to certain model limitations.

1. The rule-based system (Table 4-7) selectively places a site in one of three classes based on how it meets the criteria. The Class 2I sites have been primarily selected based on size (Rule 1) or absence of on-site activities (Rule 7 & 8) and are considered to be neutral and no further investigation or analysis is required. The Class 3 and Class 1 sites are selected firstly based on the existence of environmental reports and secondly on the presence of potentially harmful activities. While the scoring system incorporates both of these classes, the highest scored site(s) may reside under the Class 3 category and require priority attention compared with the highest scoring Class 1 site which should be automatically transferred to the next stage of the Framework. A means of re-classifying Class 3 sites is still required
2. The score for each site is based on a relative ranking methodology. That is, each site in the data set is compared with the others and if the data set changes in any manner (addition or removal of sites, or modification of existing data) the score will reflect that change.
3. The scoring system is based on a number of default assumptions (activity classifications, risk weights and assignments, preference factors, and maximum source, pathway and receptor scores) that, if altered would produce a different outcome. These default assumptions were made based upon the knowledge and expertise of the decision makers. As knowledge and expertise change, the default assumption may also change. However, it is imperative that once the values desired are selected they remain unchanged for the analysis period and a record of the set-points be retained for repeat analyses and documentation reporting

purposes. Modification of these weights will cause the overall scores to change and ultimately affect the site rankings.

4. The remaining limitation of the Level 1 system is with its direct use. It was designed to assess portions of a dataset based on the discretion of the decision makers. While handling the data in stages appears to be a logical approach, the concern is that sites that are ranked lower in a given dataset may in fact rank higher if included and reassessed with another dataset. Consideration should be given to incorporating all but a select number of top ranking sites from the current analysis into the following analysis (i.e. carry-over). If the size of the dataset is a concern, a lower boundary score could be set where sites scoring below this value are considered to be “*not substantially compromised*” and are removed from further comparative analyses.

## **4.8 CASE STUDY**

Level 1 of the multi-level Decision-Support System for Contaminated Site Management was developed as an Excel Macro-based classification and ranking system. The macro was applied to seventeen real sites for the purpose of prioritizing those that require a Phase I Environmental Site Assessment. The data for these sites was provided by The City of Calgary.

### ***4.8.1 Site Descriptions***

The sites selected were from all quadrants of the City of Calgary (i.e. NW, NE, SE, and SW) to insure a sufficient variation in the screened data was obtained. Land use designations included Direct Control (DC), which permits a wide range of “custom made” uses approved at the discretion of the municipality, residential, light industrial, parks and recreation, and urban reserve. Property uses included single and multi-residential, institutional, industrial, recreational, municipal and environmental reserves. According to the Level 1 screening methodology, it is recommended that a reasonable number of potentially contaminating activities and sources associated with a site be identified, both onsite and within a selected buffer region. The buffer region selected for these data was 100m from the subject property line. A maximum of three onsite and six offsite (within 100m) activities were identified for each site; selection was based on the risk categories provided in Table 4-6 with the higher risk activities obtaining priority. Potable and ecological water bodies and water wells were identified both on and off-site. Surficial geology was primarily identified as gravel. The site specific (screened) data is provided in Appendix A.

### ***4.8.2 Results & Discussion***

The Level 1 Classification and Ranking Macro was run using the site specific data in Appendix A and assigned weights provided in Appendix B. The weights are assigned by the user prior to data analysis. The sites were first identified as Class 1, 2I or 3 based on the rules in Table 4-7. Class 1 and Class 3 sites proceeded through the next phase, the

scoring system, as a single dataset generating a total score for each site. The sites were then ranked within their own classification system; comparing Class 1 against Class 1 values and Class 3 against Class 3 values. The final results of this portion of the DSS are presented in Table 4-21, Table 4-22, and Table 4-23. The output of the Macro provides a summary of the rule triggered for classification and the specific reasoning/cause, the total site score and the class rank. Table 4-24 provides a summary of the intermediate values calculated for the source and receptor components during the scoring portion of the methodology as well as the pathway score, total site score and class rank. The sites are listed from highest to lowest total score, regardless of classification.

Of the sites examined, almost all of the Class 3 sites scored higher than the Class 1 sites. Table 4-23 indicates that these top sites were placed in the Class 3 category due to the existence of reports associated with the site and/or within the buffer region. The report associated with the highest ranked site (#13) is a Remediation Plan indicating that contamination had been identified and the site had advanced to the remediation stage. Given that this is one of two sites investigated undergoing remediation, the high score achieved is validated. Site #16, although advanced to a remediation stage, has a lower ranking than Site #13. Comparison of the source, pathway and receptor scores listed in Table 4-24 indicates that while Site #16 has a markedly higher source score than Site #13, the pathway and receptor scores are markedly less. Although the source score is high, if there is little potential for movement to little or no receptors, the overall concern for the site is less. Thus, the pathway and receptor scores are the contributing factors that have reduced Site #16's expected rank position. It should be noted that, while these sites are undergoing remediation, the overall score is not a reflection of the work being done at the site but rather an indication of the *potential for contamination concern* given the known activities, water bodies/wells and hydrogeologic conditions associated with the site.

According to Table 4-23, all but two of the sites had some form of report generated specifically for the site resulting in the Class 3 categorization. If these reports had not been previously generated, the sites would have been identified as Class 1 and based on the

scores would have received priority for advancement to a Phase I ESA. This validates the scoring system developed for the Level 1 Classification and Ranking of Contaminated Sites.

Comparison of Site #7 and Site #8 (Class 1 sites) illustrates the difficulty associated with prioritizing similar sites. The total scores for these sites differ by approximately 0.03 points, with the receptor and pathway scores being identical. Neither site has activities occurring on-site but both have identical off-site activities and sources identified. The criterion that differentiates these sites is the distance of the sources/activities to the site; 77m for Site #7 and 81m for Site #8. As the distance is less for Site #7, it scores higher and is ranked higher than Site #8 providing further validation of the scoring system developed.

**Table 4-21: Level 1 Classification & Ranking Results – Class 1**

| Site# | District | Property Use      | Class   | Cause   | Report | Report Type | Rule Triggered | Score | Rank |
|-------|----------|-------------------|---------|---|--------|-------------|----------------|-------|------|
| 17    | CDG      | Multi-residential | Class 1 | No Report & High Risk PCA(s) or Foreign Utility Well on Site(s) within 100m | n/a    | n/a         | Rule 5         | 41.23 | 1    |
| 9     | CDBR     | Multi-residential | Class 1 | Source on Site  | n/a    | n/a         | Rule 3         | 39.01 | 2    |
| 6     | CDWP     | institutional     | Class 1 | Source on Site  | n/a    | n/a         | Rule 3         | 32.96 | 3    |
| 7     | CDBR     | recreational      | Class 1 | No Report & High Risk PCA(s) or Foreign Utility Well on Site(s) within 100m | n/a    | n/a         | Rule 5         | 31.76 | 4    |
| 8     | CDBR     | recreational      | Class 1 | No Report & High Risk PCA(s) or Foreign Utility Well on Site(s) within 100m | n/a    | n/a         | Rule 5         | 31.72 | 5    |



**Table 4-22: Level 1 Classification & Ranking Results – Class 2I**

| Site# | District | Property Use       | Class    | Cause  | Report | Report Type | Rule Triggered | Score | Rank |
|-------|----------|--------------------|----------|--|--------|-------------|----------------|-------|------|
| 1     | CDGIP    | single residential | Class 2I | No Report within 100m, No Sources On-site/within 100m        | n/a    | n/a         | Rule 8         | n/a   | n/a  |
| 2     | CDW      | municipal reserve  | Class 2I | No Report within 100m, ONLY Lower Risk PCA's > 25m from site | n/a    | n/a         | Rule 7         | n/a   | n/a  |
| 3     | CDO      |                    | Class 2I | Area < 0.05acre(202m <sup>2</sup> )                          | n/a    | n/a         | Rule 1         | n/a   | n/a  |
| 4     | CDO      |                    | Class 2I | Area < 0.05acre(202m <sup>2</sup> )                          | n/a    | n/a         | Rule 1         | n/a   | n/a  |
| 5     | CDFI     |                    | Class 2I | Area < 0.05acre(202m <sup>2</sup> )                          | n/a    | n/a         | Rule 1         | n/a   | n/a  |

**Table 4-23: Level 1 Classification & Ranking Results – Class 3**

| Site# | District | Property Use          | Class   | Cause   | Report                         | Report Type                             | Rule Triggered | Score | Rank |
|-------|----------|-----------------------|---------|---|--------------------------------|---|----------------|-------|------|
| 13    | CDRW1    | industrial            | Class 3 | Report for Site                                     | Report for Site                | Remediation Plan                        | Rule 2         | 64.87 | 1    |
| 12    | CDRW1    | institutional         | Class 3 | Report for Site                                     | Report for Site                | Combo Phase I&II                        | Rule 2         | 63.83 | 2    |
| 11    | CDRW2    | institutional         | Class 3 | Report for Site                                     | Report for Site                | Phase II                                | Rule 2         | 58.26 | 3    |
| 10    | CDMI     | single residential    | Class 3 | Report for Site                                     | Report for Site                | Further Work Supplemental Investigation | Rule 2         | 53.75 | 4    |
| 16    | CDGIP    | industrial            | Class 3 | Report for Site                                     | Report for Site                | Remediation Plan                        | Rule 2         | 50.73 | 5    |
| 14    | CDE      | environmental reserve | Class 3 | Report for Site(s) within 100m & No Sources on-site | Report for Site(s) within 100m | Phase I                                 | Rule 4         | 44.72 | 6    |
| 15    | CDBI     | single residential    | Class 3 | Foreign Utility Pipeline ONLY on-site               |                                |   | Rule 3         | 35.71 | 7    |

**Table 4-24: Level 1 Classification & Ranking Results – Score Review**

| Site# | Class    | Source Score (Max 38 Pts) |                   |              | Pathway Score (Max 30 Pts) | Receptor Score (Max 32 Pts) |                   |                          |                | Total Score | Rank |
|-------|----------|---------------------------|-------------------|--------------|----------------------------|-----------------------------|-------------------|--------------------------|----------------|-------------|------|
|       |          | Onsite Component          | Offsite Component | Source Total |                            | Onsite Component            | Offsite Component | Land Use Receptor Factor | Receptor Total |             |      |
| 13    | Class 3  | 3.47                      | 1.47              | 2.87         | 30.00                      | 1.00                        | 1.00              | 1.00                     | 32.00          | 64.87       | 1    |
| 12    | Class 3  | 18.43                     | 3.23              | 13.87        | 30.00                      | 0.20                        | 0.36              | 1.00                     | 19.96          | 63.83       | 2    |
| 11    | Class 3  | 20.79                     | 19.01             | 20.26        | 30.00                      | 0.00                        | 0.00              | 0.50                     | 8.00           | 58.26       | 3    |
| 10    | Class 3  | 1.64                      | 38.00             | 12.55        | 30.00                      | 0.00                        | 0.00              | 0.70                     | 11.20          | 53.75       | 4    |
| 16    | Class 3  | 38.00                     | 19.80             | 32.54        | 14.00                      | 0.00                        | 0.21              | 0.20                     | 4.19           | 50.73       | 5    |
| 14    | Class 3  | 0.00                      | 1.48              | 0.45         | 30.00                      | 0.00                        | 0.64              | 0.70                     | 14.27          | 44.72       | 6    |
| 17    | Class 1  | 0.00                      | 17.44             | 5.23         | 20.00                      | 0.00                        | 0.00              | 1.00                     | 16.00          | 41.23       | 1    |
| 9     | Class 1  | 1.73                      | 5.98              | 3.01         | 20.00                      | 0.00                        | 0.00              | 1.00                     | 16.00          | 39.01       | 2    |
| 15    | Class 3  | 1.64                      | 11.20             | 4.51         | 20.00                      | 0.00                        | 0.00              | 0.70                     | 11.20          | 35.71       | 7    |
| 6     | Class 1  | 1.76                      | 15.77             | 5.96         | 11.00                      | 0.00                        | 0.00              | 1.00                     | 16.00          | 32.96       | 3    |
| 7     | Class 1  | 0.00                      | 1.86              | 0.56         | 20.00                      | 0.00                        | 0.00              | 0.70                     | 11.20          | 31.76       | 4    |
| 8     | Class 1  | 0.00                      | 1.74              | 0.52         | 20.00                      | 0.00                        | 0.00              | 0.70                     | 11.20          | 31.72       | 5    |
| 1     | Class 2I |                           |                   |              |                            |                             |                   |                          |                | n/a         | n/a  |
| 2     | Class 2I |                           |                   |              |                            |                             |                   |                          |                | n/a         | n/a  |
| 3     | Class 2I |                           |                   |              |                            |                             |                   |                          |                | n/a         | n/a  |
| 4     | Class 2I |                           |                   |              |                            |                             |                   |                          |                | n/a         | n/a  |
| 5     | Class 2I |                           |                   |              |                            |                             |                   |                          |                | n/a         | n/a  |

#### **4.8.3 Conclusion**

Level 1 of the multi-level Decision Support System Model Framework (Figure 3-1) involves the identification, classification and ranking of sites *for* Phase I Environmental Site Assessments (ESA). The system developed provides a means of comparing a large number of sites with a vast amount of data based on several criteria in order to prioritize actions to be taken. The scoring system is composed of three main components, source, pathway and receptor providing a potential overall score of 100 points. According to the dataset examined in the case study, the maximum score attained was 64.87 out of a possible 100 points and this site was already undergoing remediation.

Since the source, receptor and pathway scores are obtained through calculations that included normalizing quantities against each other (i.e. quantity factors), it is highly unlikely that one site would obtain the maximum number of points allotted for each component and therefore a perfect score of 100 may never be attained. The score provides an understanding of the site conditions and an indication of the potential concern associated with that site and will change depending on the dataset used. Therefore, the methodology provides a relative rank and not an absolute rank.

The case study validated the scoring system by scoring those sites that have already had investigative reports performed and advanced to the remediation stage above the remaining sites in the dataset. Further validation in the methodology was observed when differentiation between almost identical sites was achieved. Since municipalities are subject to budgetary constraints, the ability to differentiate between nearly identical sites contained within a vast amount of information is extremely important and the methodology herein developed will serve as a valuable tool for decision makers.

## CHAPTER FIVE: LEVEL 3 - FURTHER CLASSIFICATION FOR SITE MANAGEMENT

### 5.1 INTRODUCTION

Following the Level 1 Classification and Ranking of Sites and subsequent progression of the priority sites to Phase I ESA's, the results of the reports are reviewed by the municipality's environmental manager(s) and the decision to advance a given site to the next phase of investigation is made. If the report indicates no further investigation is required, the site is reclassified from Class 1 to Class 2I. If, however, further investigation is indicated, the site remains a Class 1 site and advances to a Phase II Environmental Site Assessment (ESA).

A Phase II ESA is employed to confirm the presence and identity of substances of concern and delineate contamination at a site. Where the Phase I ESA is a non-invasive investigative examination of a property, the Phase II ESA is invasive and involves the use of quantitative sampling and analytical techniques (Canadian Standards Association 2000). The level of assessment is guided by the information available. In some cases Phase II ESA's can be iterative to obtain additional information but the cost and time of obtaining that information may outweigh the use of the information and lead to cost overruns. (Nielsen et al. 2005)

The information provided in the site reports can be numerical or linguistic in nature, and will include a large amount of data. When a site manager has only a single site under assessment, review of the report is relatively simple in that the decision made reflects the clarity of the consultant's findings and recommendations. However, when a large number of sites are being investigated simultaneously, the ability to prioritize the sites based on the data becomes increasingly difficult as the number increases.

The most common approach to prioritizing actions is to rate projects based on relevant criteria and perception of urgency. In terms of environmental management, priority is often assigned based on the results of risk assessments, regulatory compliance requirements, public risk perception, and cost. Municipal Environmental Site Managers currently evaluate all of the information available to prioritize their actions but often the documentation of the process is not complete as the decisions are made based on the professional judgment of the site manager(s) at the time. In order to ensure consistency in interpretation of results and documentation of the decision making process a scientifically defensible, standardized means of analyzing the information is required. The method selected should make use of available theory, scientific knowledge and expert opinion. It should define and categorize the risks to be ranked, identify the relevant elements and record the results in standardized risk summary sheets for ease of review (Florig et al. 2001).

Five major criteria, of varying levels of influence, have been identified as the foundation for prioritizing environmental site management activities and each of the criteria are comprised of several elements. In order to account for all of the elements, a Multi-Criteria Decision Making Model (MCDM) is recommended and developed for the final level of the DSS Model Framework: Level 3 – Further Classification for Site Management. This chapter provides a detailed description of the methodology developed and a case study to illustrate the application of the MCDM.

## **5.2 OVERVIEW**

When a site assessment has advanced along the DSS Model Framework (Figure 3—1) to the second level and requires a Phase II ESA, the municipality commissions the work to an outside Consultant/Assessor. The scope of the work and the information required in the final report may be established with the assistance of the selected Assessor, or may be pre-defined in the form of a “Terms of Reference” document (Canadian Standards Association 2000; The City Of Calgary 2005). The specific site information requested can include:

**Table 5-1: Phase II Site Assessment Information**

|                                      |                                     |
|--------------------------------------|-------------------------------------|
| Site Dimensions                      | Hydraulic Conductivity              |
| Legal description/ Municipal address | Groundwater Flow direction          |
| Local Zoning                         | Groundwater Gradient                |
| Adjacent properties & land use       | Presence of phase-separated product |
| Surface Water bodies within 300m     | Presence of controlled substance    |
| Water wells within 500m radius       | Soil Chemistry                      |
| Depth to Groundwater                 | Surface Water Chemistry             |
| Borehole logs                        | Ground Water Chemistry              |
| Soil Descriptions (USCS)             | Exceedance identification           |

The proposed multi-criteria model will take the information provided in the Phase II ESA reports and combine select data to ultimately obtain a single site score that can be used for ranking. The foundation of the model is based on the risk assessment paradigm. The two most common assessments relate to human health and ecological impacts. To date, there is no standardized methodology that combines the two in a single score; separate values are obtained and the combination/interpretation is left to the decision maker's professional judgment. The MCDM herein developed, utilizes the existing scientifically defensible models and approaches associated with the risk assessment paradigms and combines the results with additional criteria to obtain a final ranking representative of the condition of a contaminated site. The final ranking does not, in itself, indicate a "risk" level but rather prioritizes action to be taken by the decision maker(s).

Five criteria (Impact Factors) have been identified using a hierarchical approach, starting with a general criterion and identifying sub-criteria down the hierarchy that are more easily subject to evaluation by the decision maker based on the results of the Phase II ESA and existing assessment models. This hierarchy is represented in Figure 5—1.

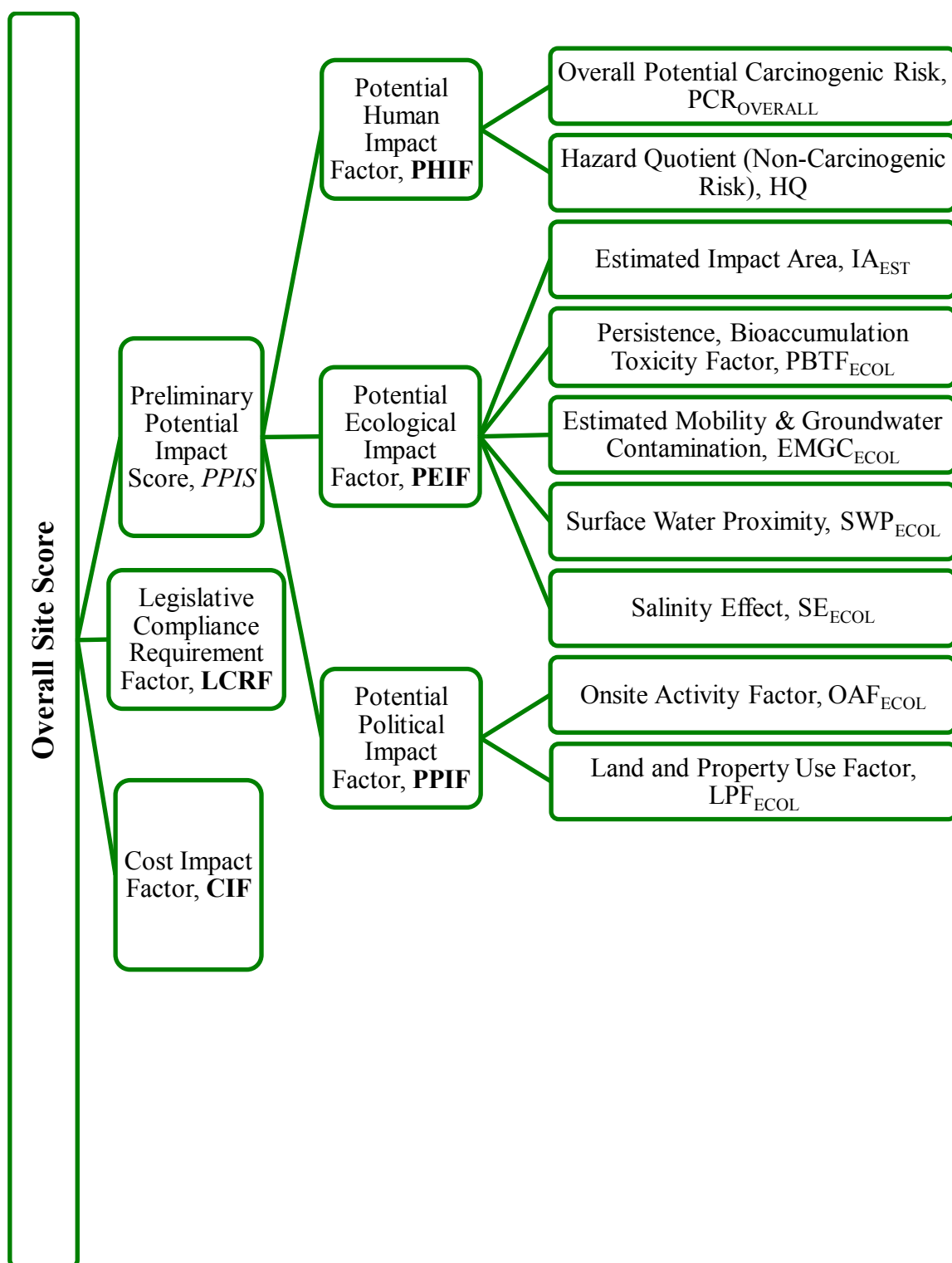


Figure 5—1: Hierarchical Identification of Level 3 Site Score Criteria



Each impact factor is evaluated based on relevant sub-criteria producing a numerical that is compared with accepted scientific or regulatory values and subsequently categorized into a low, medium or high level of concern. These values are then linearly transformed into the generic levels of concern developed for the Level 1 Classification and Scoring System (Table 4-8). It is the combination of these intermediate scores that produces the final Overall Site Score and ranking.

The MCDM model involves a four stage process:

1. Site Classification
2. Class modification
3. Ranking
4. Cost Ranking

Site classification focuses on combining the results from the investigation of three of the impact factors (PHIF, PEIF, PPIF) into a Preliminary Potential Impact Score (PPIS) which is used to classify the contaminated site into one of several site management categories:

Class A: Remediation required immediately

Class B: Remediation required but can be delayed temporarily

Class C: Long term monitoring (Risk Management) required

Class D: Low risk, intermittent monitoring required

Class E: Further investigation required (insufficient data), and

Class 2II: no further investigation required.

The results of each of the impact factors are weighted based on a pre-determined level of importance and then summed to provide the PPIS:

**Equation 5–1: Preliminary Potential Impact Score, *PPIS***

$$PPIS = PHIF \times PHIF_{WEIGHT} + PEIF \times PEIF_{WEIGHT} + PPIF \times PPIF_{WEIGHT}$$

where,

PHIF = Potential Human Impact Factor

PEIF = Potential Ecological Impact Factor

PPIF = Potential Political Impact Factor

WEIGHT = “Weight of Importance” value associated with specific Impact Factor

The *weights of importance* assigned to the impact factors are based on professional judgment and are presented in Table 5-2. For the methodology developed, the hierarchical scheme indicates that three main components are used to derive the overall final site score: PPIS, LCRF and CIF. As the PPIS is a combination of three impact factors, the weights for these impact factors were selected to total 1.0. Variations in the numbers reflect the usage of parameters in the derivation of the impact factors; some of the parameters required for the evaluation of the PEIF and PIF are already used in the PHIF and therefore the weightings for these are less than the PHIF. These weights can be changed at the discretion of the decision maker(s) prior to implementing the MCDM.

**Table 5-2: MCDM Impact Factors/Criteria and Weightings**

| <b>Impact Factor/Criteria</b>                   | <b>Weight of Importance</b> |
|---|-----------------------------|
| Potential Human Impact Factor, PHIF             | 0.40                        |
| Potential Ecological Impact Factor, PEIF        | 0.35                        |
| Political Impact Factor, PIF                    | 0.25                        |
| Legislative Compliance Requirement Factor, LCRF | 1.0                         |
| Cost Factor, CF                                 | 0.8                         |

The second stage involves modification of the class based on the inclusion of the Legislative Compliance Requirement Factor. The weighting assigned to the LCRF is 1.0 as regulatory compliance is mandatory. The inclusion of this factor should automatically promote the site to Class A, regardless of the PPIS.

Development of the scoring ranges for site classification is based on a combination of the potential scores that could be attained and a Level of Concern Scale, similar to that used in Level 1. The maximum PPIS attainable is 1.0 and is indicative of maximum potential human, ecological and political impacts on the site due to contamination. This value/score should represent one of the *required remediation* category boundaries (Class A or B). Since application of the LCRF to any PPIS score greater than zero would result in a value greater than 1.0, and application to a maximum PPIS would produce a maximum value of 2.0, the boundary between Class A and Class B is set at 1.0. The lower boundary of Class B and score ranges for Class C, D and 2III are determined based on a slightly modified Level of Concern Scale. No score range is provided for Class E designated sites since further investigation may be required to obtain additional data and the score obtained is not a true representation. The final scoring ranges selected for classification of contaminated sites are provided in Table 5-3.

**Table 5-3: Site Classification**

| <b>Class Designation</b> | <b>Class Description</b>                            | <b>Score Range</b>      |
|--------------------------|---|-------------------------|
| A                        | Remediation required immediately                    | $1.00 \leq x \leq 2.00$ |
| B                        | Remediation required but can be delayed temporarily | $0.70 \leq x < 1.00$    |
| C                        | Long term monitoring (Risk Management) required     | $0.50 \leq x < 0.70$    |
| D                        | Low risk, intermittent monitoring required          | $0.20 \leq x < 0.50$    |
| E                        | Further investigation required (insufficient data)  | n/a                     |
| 2III                     | no further investigation required                   | $x < 0.20$              |

Once the final class designation is assigned, the sites are ranked in each category to facilitate identification of those that should be sent out for cost estimates. Class A site remediation is mandatory due to legislative compliance requirements therefore costing must be determined for all sites. Estimate requests for Class B, C and D sites are based on the remaining budgetary allotment for contaminated site management.

The final stage involves the application/inclusion of the Cost Impact Factor to obtain the Overall Site Score and rank. A value of 0.8 was designated for the CIF weight to signify that the conditions at the site predominates prioritizing action but cost undoubtedly has an important role. The weighted CIF is added to the final score obtained following the class modification stage:

**Equation 5–2: Overall Site Score (OSS)**

$$OSS = \text{Final Class Score} + (CIF \times CIF_{WEIGHT})$$

where,

Final Class Score = *PPIS + LCRF (Legal Compliance Requirement Factor)*

CIF = Cost Impact Factor

CIF<sub>WEIGHT</sub> = Cost Impact Factor “Weight of Importance” (Table 5-2)

Ranking of the sites is performed independently for each Class designation and represented in descending order. While the ranking provides guidance, the actual prioritization of action will still be at the discretion of the decision maker(s) based on budgetary constraints of the department.

### 5.3 SITE SCREENING

Screening involves the collection and tabulation of information from the Phase II ESA reports on property owned and/or operated by a municipality. The sites undergoing this level screening have been previously identified as being within an area of concern through the first two levels of the Model Framework. The data to be entered will be very detailed and a standardized format has been developed using an MS-Excel macro based program. The macro is designed to search and retrieve the relevant information from the Level 1 Database as well as the MCDM database (for duplicate entries) based on the municipality’s unique property identification number to reduce the data input requirements and ensure consistency in data entry. The process can be further expedited

by modification to the “Terms of Reference” document whereby the Consultant/Assessor can complete a standard form summarizing the information required for entry.

Previously screened data that will be required include the spatial identifiers (Table 4-1), *on-site* sources (Table 4-2), geology, and hydrology. If the site has not been screened, this information will need to be collected and recorded for the Level 3 assessment process. Additional screening data is listed in Table 5-4.

**Table 5-4: Additional Screening Data**

|   |   |                             |
|---|---|-----------------------------|
| Date  | Screening Date                                  |                             |
|   | Report Date                                     |                             |
| Estimated Impact Area(m <sup>2</sup> )                |   |                             |
| Exceedance Reported                                   | Soil  |                             |
|   | Groundwater                                     |                             |
|   | Both  |                             |
| Neighbouring Properties<br>(North, East, South, West) | Property Use Designation                        | Alberta Environment Generic |
|   |   | Municipality                |
|   | Municipality Land Use Designation (Zoning Code) |                             |
|   | Reference Address                               |                             |
| Hydrology   | Onsite Quantity                                 |                             |
|   | Offsite Quantity in Three Buffer Regions        | 0-100m                      |
|   |   | 100-200m                    |
|   |   | 200-300m                    |
| Phase II Soil & Groundwater Testing Results           |   |                             |

## 5.4 CLASSIFICATION OF SITES AFTER SCREENING

As mentioned in Section 5.2, site classification and modification focuses on combining the results from the investigation of the Potential Human, Ecological and Political Impact factors, with the Legal Compliance Requirement Factor to obtain a score that places the contaminated site into one of several site management categories.

An ideal score assignment should represent the exact situation observed at the site and transmit it to the decision-makers without loss of information. Ideally, one would like to consider linguistic expressions that can describe conditions at the site as high, medium or low risk and transform them into numeric values that can be used to produce a score that will ultimately rank the sites. The transformation will be two-fold. The values obtained through the use of mathematical expressions will be first placed into linguistic categories (high, medium, and low) and then, based on the appropriate category, transformed into a prorated value between the associated boundaries. The basic value ranges selected in the Level 1 Rule-Based Methodology to represent high, medium and low perceived risk levels associated with potentially contaminating activities and property/land use designations will be utilized in the Level 3 MODM to maintain consistency.

### 5.4.1 *Exceedance Evaluation*

Estimation of the potential impact on humans and the environment is performed based on the contaminants of concern (COC) present at the site under investigation. Typically, the contaminants of concern are those that pose the greatest hazard to the inhabitants and these are generally selected from the vast mixture of chemicals that are identified at a site. Selection is based on chemical classes, frequency of detection and a concentration toxicity screen (USEPA 1989). When dealing with a single site, this is relatively easy to accomplish but when dealing with the large number of sites, the task of isolating COC's would be extremely time consuming and logistically cumbersome as the reasoning for eliminating chemicals from the risk assessment should be clearly identified. Thus, since the properties under assessment are vast in number and vary in activity the quantitative evaluation of all chemicals detected in exceedance will be performed. Exceedance is

based on a comparison of the sample concentrations with the acceptable regulatory (Federal, Provincial and Municipal) guidelines for soil and groundwater concentrations and background concentrations found at or near the site (AENV 2008b; c). Background concentrations are only applicable to naturally occurring inorganic chemicals as the majority of organic chemicals found at a site are anthropogenic in nature.

#### ***5.4.2 Potential Human Impact Factor (PHIF)***

Evaluation of the Potential Human Impact Factor, PHIF is based on a comprehensive exposure assessment of the site under investigation. The exposure and risk assessment process can be qualitative or quantitative and involve the evaluation of the magnitude, frequency, duration and route of exposure to chemicals at a site (USEPA 1988). The process involves four basic steps:

1. Identify basic site characteristics (geology; hydrology; presence and location of surface water bodies, populations on or near the site, population activity patterns, site usage(zoning))
2. Identify exposure pathways (based on sources, releases and types of chemicals at the site; environmental fate (persistence, partitioning, transport) and routes of exposures (ingestion, inhalation, dermal) for each pathway)
3. Quantify the magnitude, frequency and duration of exposure for each pathway (estimate exposure/intake)
4. Estimate risk (carcinogenic and non-carcinogenic)

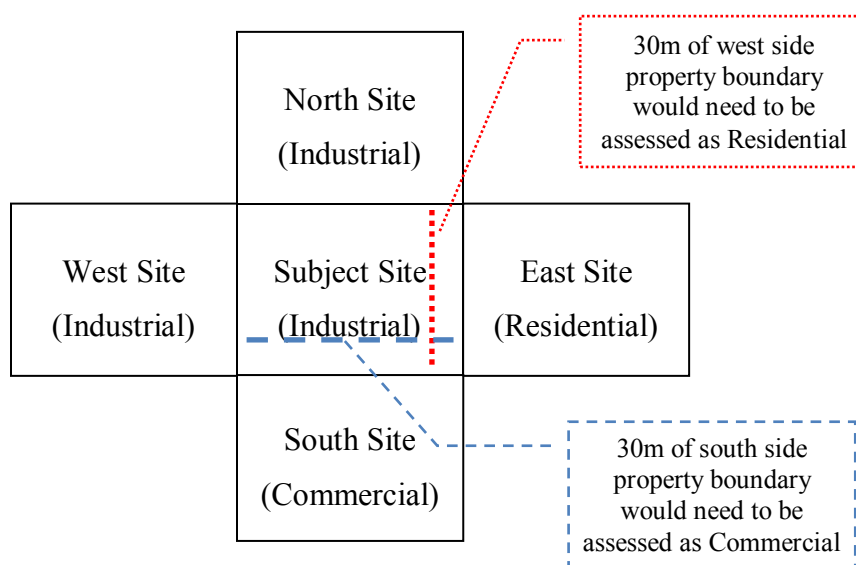
The Alberta Tier1/Tier 2 Soil and Groundwater Remediation Guidelines (AENV 2008b; c) provide numerical targets for remediation of contaminated soil and groundwater. The values are NOT “pollute-up-to” levels but provide guidance to landowners and/or site managers to prevent potential loss of land use options. The numerical values provided are for the most sensitive receptors present at the site and are specific for soil type (coarse and fine grained) and five different types of land use:

1. *natural area* = area away from human habitation and activities, where the primary concern is the protection of ecological receptors,
2. *agricultural* = primary land use is growing crops or tending livestock as well as human residence,
3. *residential/parkland* = primarily residential or recreational activity (includes campground areas and urban parks)
4. *commercial* = primary activity is commercial where unrestricted access is available to all members of the public, and
5. *industrial* = primary activity is the production, manufacture or construction of goods

To select the most appropriate guideline value for a site, the current land use(s), activity patterns and future land use(s) must be taken into account. When municipal zoning incorporates more than one land use scenario, the most conservative (more sensitive) land use description must be applied.

The guideline documents developed in Canada (AENV 2008a; b; c; CCME 2006) and the United States (USEPA 1989) for performing risk assessments all indicate that those populations that are closest to or actually living on the site have the greatest potential for exposure. They recommend that the land uses of adjacent or nearby properties be documented and the most sensitive should be used in the assessment. Alberta Environment provides a 30m boundary range on the contaminated subject property when it is less sensitive than a neighboring property wherein the guidelines for the more sensitive boundary should be applied. A possible scenario is shown in the figure below. An industrial site is bordered by two industrial properties, a commercial property and a residential property.





**Figure 5—2: Zoning/Exposure Scenario**

If the size of the subject site is such that the 30m boundary covers a significant portion of the site, the site should be treated and assessed as the most sensitive zoning (i.e. residential in the given scenario). If the opposite is true, the contribution from the residential and commercial boundaries would be relatively insignificant. When dealing with several municipal properties at the same time, the assessment procedure can become laborious if a general rule is not developed. If all the subject properties are all considered “small”, then the most sensitive property zone would be selected and applied to the subject property. This would not provide an adequate means of classifying the risk associated with the properties as all sites are located within a municipality and the chances that a “higher risk/more sensitive” –type zoning neighbouring a less sensitive property is relatively high and the assessment would be considered overly conservative and not necessarily reflective of the property. The values provided in the Tier 1 guidelines are such that the property under investigation would be remediated to the current zoning or possible future zoning.

In order to streamline the process and ensure that all receptors are accounted for and protected, all 5 sites (subject site and the four neighboring sites) should be included in the risk

assessment process. Exposure estimates are evaluated based on the property zonings and associated sensitive receptors and prorated. The subject property contributes 60% to the overall exposure and each of the adjacent properties 10% (total 40% for offsite effect).

Exposure estimates/intakes are expressed in terms of the mass of substance in contact with the body per unit body weight per time (e.g. mg chemical per kg body weight per day, mg/kg-day) and are calculated using equations that include variables for exposure concentration, contact rate, exposure frequency, exposure duration, body weight, and exposure averaging time. The values for these variables depend on the site conditions, the exposed population and the toxicity classification of the COC (carcinogenic vs. non-carcinogenic).

The method typically used for determining the effect of contaminated soil and/or groundwater is through the calculation of potential intake of the contaminant of concern by humans via three pathways:

1. Dermal contact
2. Inhalation
3. Ingestion

Several models have been developed for estimating daily intake/dose exposure rates. The basic underlying formula (Health Canada 2004a) is represented as:

**Equation 5–3: Estimated Daily Intake, EDI**

$$EDI = \sum_{i=1}^3 ED_i = \sum_{i=1}^3 \frac{C \times CR \times BF \times EF}{BW}$$

where,

EDI = Estimated Daily Intake (mg/kg-day)

ED<sub>i</sub> = Exposure Dose estimate from pathway, *i* (ingestion, inhalation, dermal)

- C = Contaminant Concentration in medium (mg/kg soil, mg/L water)
- CR = Contact Rate (e.g. L/day, mg/day)
- BF = Bioavailability Factor (unitless)
- EF = Exposure frequency (events/yr) x exposure duration (years/lifetime)
- BW = Body weight (kg)

The EDI represents the total intake of a specific contaminant and is the summation of the individual exposure doses from various potential pathways (ingestion, inhalation and/or dermal) for a given contaminant of concern. The exposure dose estimate from a pathway is specific to the most sensitive receptor, the toxicity (carcinogenic or non-carcinogenic) and bioavailability of the contaminant and the exposure period (frequency, duration and intensity). Identification of potential receptors depends on the land use (agricultural, residential/parkland, commercial and industrial) and may include individuals from all age groups from which the most sensitive is derived based on the group that is determined to have the greatest exposure to a COC per unit of body weight per day. In general, CCME identifies adults as the most sensitive receptor for non-threshold (carcinogenic) substances since the exposure is considered continuous over 70 years and toddlers (6 months to 4 years) as the most sensitive for threshold (non-carcinogenic) substances where exposure is averaged over the most sensitive life stage. A summary of the exposure assumptions for the various general land use scenarios is provided in the following table. (CCME 2006)

**Table 5-5: Exposure Assumptions for Defined Land Use Scenarios**

| GENERALIZED<br>LAND USE<br>DESIGNATION                  | SENSITIVE<br>RECEPTOR                                  | EXPOSURE<br>PERIOD                          | EXPOSURE PATHWAYS                    |   |
|---|--|---|--------------------------------------|---|
| Agricultural  | Toddler<br>(threshold)<br>Adult (non-<br>threshold)    | 24hours/day<br>365 day/year                 | Soil                                 | Ingestion<br>Dermal Contact<br>Particulate Inhalation |
|   |  |   | Groundwater                          | Ingestion<br><i>Dermal*</i>                           |
|   |  |   | Consumption of produce, meat, milk** |   |
|   |  |   | Volatilization into indoor air**     |   |
| Residential /<br>Parkland                               | Toddler<br>(threshold)<br><br>Adult<br>(non-threshold) | 24hours/day<br>365 day/year                 | Soil                                 | Ingestion<br>Dermal Contact<br>Particulate Inhalation |
|   |  |   | Groundwater                          | Ingestion<br><i>Dermal*</i>                           |
|   |  |   | Consumption of produce**             |   |
|   |  |   | Volatilization into indoor air**     |   |
| Commercial  | Toddler<br>(threshold)<br><br>Adult<br>(non-threshold) | 10 hours/day<br>5 day/week<br>48 weeks/year | Soil                                 | Ingestion<br>Dermal Contact<br>Particulate Inhalation |
|   |  |   | Groundwater                          | Ingestion<br><i>Dermal*</i>                           |
|   |  |   | Volatilization into indoor air**     |   |
| Industrial  | Adult<br>(threshold)<br><br>Adult<br>(non-threshold)   | 10 hours/day<br>5 day/week<br>48 weeks/year | Soil                                 | Ingestion<br>Dermal Contact<br>Particulate Inhalation |
|   |  |   | Groundwater                          | Ingestion<br><i>Dermal*</i>                           |
|   |  |   | Volatilization into indoor air**     |   |
| * pathway not specified by CCME(2006) – see text        |  |   |                                      |   |
| ** pathway not applicable in current project – see text |  |   |                                      |   |

In the event that a “potable water well” is identified as existing on, or within 100m of, the site under investigation it is assumed that the inhabitants of the property are utilizing this water source. Therefore, in addition to ingestion of potentially contaminated water, dermal exposure will also be incorporated into the exposure assessment process.

Indirect exposure to contaminants in soil is known to occur through food chain contamination. According to the CCME an estimated 10% of all fruits and vegetables consumed in residential districts are home-grown whereas in agricultural districts an estimated 50% of all fruits and vegetables, 50% of the meat, and 100% of the milk consumed are produced on site (CCME 2006). Evaluation of exposure dose for residential and agricultural properties with regard to food chain contamination requires analysis of the food ingested for specific contaminant levels. This level of investigation is not currently performed unless a specific issue or concern exists and therefore will not be included in the PHIF evaluation.

During a Phase II site assessment, the measurement of volatile organic compounds is generally completed by a downhole measuring device with the results presented on the borehole log documents. The results of this investigation are overall parts per million (ppm) levels of volatiles with no specific identification or quantification of the volatile compounds involved and thus exposure dose evaluation of volatiles into indoor air are not included in the PHIF evaluation at this time.

A modification to the exposure/intake formulas is recommended to more accurately reflect the degree of soil exposure. This involves the development and use of a “*Zone Factor*” that would act as a ‘proportionality constant’ to be applied to the contaminant concentration detected at the site. As the majority of the property within a municipality is covered with some form of impermeable groundcover (buildings, asphalt, slab or block concrete), the general assumption would be that exposure to contaminated soil is reduced and significant differentiation between the sites would not be achieved. If, however, an assumed degree of dermal exposure is incorporated into the intake portion of the formulas based on the % groundcover associated with each site some additional differentiation may be achieved that

will facilitate prioritization of the sites. The City of Calgary Land Use Bylaw (The City of Calgary 2008 (May 2010 Update)-a) lists information regarding permitted and discretionary uses and development rules (minimum standards) for each land use district, including maximum site coverage by buildings, etc. and/or minimum site landscaping required for each of the districts. The results of the review are presented in Table 5-6 to Table 5-13. Note that some of the tables provide minimum landscape coverage and some provide maximum parcel coverage (buildings, etc).

**Table 5-6: Industrial Districts Minimum Landscape Coverage**

(The City of Calgary 2008 (May 2010 Update)-a)

| CITY OF CALGARY LAND USE   |         | % PARCEL<br>COVERAGE   | CITY OF CALGARY<br>LAND USE BYLAW<br>1P2007 SECTION |
|--|---------|--|---|
| DISTRICT DESCRIPTION   | CODE(S) |  |   |
| General  | I-G     | Setback area   | 918   |
| Business   | I-B     | Setback area<br>+ 15 (parking areas<br>>5000m <sup>2</sup> ) | 932 - 934, 93(1)                                    |
| Edge   | I-E     | Setback area   | 949 - 950   |
| Commercial   | I-C     | Setback area   | 964 - 965   |
| Redevelopment  | I-R     | Setback area   | 978 - 979   |
| Outdoor  | I-O     | *90% (max incl.<br>setback area)                             | 986-987, 993  |
| Heavy  | I-H     | Setback area   | 1006  |
| * 90% refers to land not covered by buildings (1600m <sup>2</sup> max building floor area / 16000m <sup>2</sup> min parcel area x 100 = 10%) |         |  |   |

**Table 5-7: Commercial Districts Minimum Landscape Coverage**  
(The City of Calgary 2008 (May 2010 Update)-a)

| CITY OF CALGARY LAND USE |                            | % PARCEL<br>COVERAGE | CITY OF CALGARY<br>LAND USE BYLAW<br>1P2007 SECTION |
|--------------------------|----------------------------|----------------------|---|
| DISTRICT<br>DESCRIPTION  | CODE(S)                    |                      |   |
| Neighborhood             | C-N1, C-N2,                | Set-back areas       | 716, 733,   |
| Community                | C-C1, C-C2                 | Set-back areas       | 751, 769  |
| Corridor                 | C-COR1, C-COR2,<br>C-COR3, | Set-back areas       | 790, 808, 824                                       |
| Office                   | C-O                        | Set-back areas       | 838   |
| Regional                 | C-R1, C-R2, C-R3           | Set-back areas       | 856, 873, 891                                       |

**Table 5-8: Centre City East Village Districts Minimum Landscape Coverage**  
(The City of Calgary 2008 (May 2010 Update)-a)

| CITY OF CALGARY LAND USE |         | % PARCEL<br>COVERAGE | CITY OF CALGARY<br>LAND USE BYLAW<br>1P2007 SECTION |
|--------------------------|---------|----------------------|---|
| DISTRICT DESCRIPTION     | CODE(S) |                      |   |
| General                  |         | 30                   | 1218(1)   |
| Recreational             | CC-ER   | See general          | See general   |
| Mixed Use                | CC-EMU  | See general          | See general   |
| Transition               | CC-ET   | See general          | See general   |
| Primarily Residential    | CC-EPR  | See general          | See general   |
| Integrated Residential   | CC-EIR  | See general          | See general   |
| River Residential        | CC-ERR  | See general          | See general   |

**Table 5-9: Residential Districts Maximum Parcel Coverage**

*(Buildings, Parking Stalls, Garbage Facilities)*  
 (The City of Calgary 2008 (May 2010 Update)-a)

| CITY OF CALGARY LAND USE |                                       | % PARCEL COVERAGE | CITY OF CALGARY LAND USE BYLAW 1P2007 SECTION |                                 |
|--------------------------|---------------------------------------|-------------------|---|---------------------------------|
| DISTRICT DESCRIPTION     | CODE(S)                               |                   |   |                                 |
| Low Density Residential  | Contextual Large Parcel One Dwelling  | R-C1L & R-C1Ls    | 40  | 375                             |
|                          | Contextual One Dwelling               | R-C1, R-C1s       | 45  | 393                             |
|                          | Contextual Narrow Parcel One Dwelling | R-C1N             | 45 - 50                                       | 412(1), 412(2)                  |
|                          | Contextual One/Two Dwelling           | R-C2              | 45  | 432                             |
|                          | One Dwelling                          | R-1, R-1s         | 45  | 453                             |
|                          | Narrow Parcel One Dwelling            | R-1N              | 45 – 60 (50)                                  | 467(1), 467(2), 467(3)          |
|                          | One/Two Dwelling                      | R-2               | 45 - 50                                       | 482(1), 482(2)                  |
|                          | Low Density Multiple Dwelling         | R-2M              | 45 - 60                                       | 497(1)(a), 497(1)(b), 497(1)(c) |
|                          | Manufactured Home                     | R-MH              | 45  | 514                             |
|                          | Cottage Housing                       | R-CH              | 50  | 534                             |
| Multi-Residential        | General Rules                         |                   | 60  | 551(3), 553, 551(5)             |
|                          | Contextual Grade-Oriented             | M-CG              | 50  | 581(1)                          |
|                          | Contextual Low Profile                | M-C1              | See general                                   | See general                     |
|                          | Contextual Medium Profile             | M-C2              | See general                                   | See general                     |
|                          | At Grade Housing                      | M-G               | See general                                   | See general                     |
|                          | Low Profile                           | M-1               | See general                                   | See general                     |
|                          | Medium Profile                        | M-2               | See general                                   | See general                     |
|                          | High Density Low Rise                 | M-H1              | See general                                   | See general                     |
|                          | High Density Medium Rise              | M-H2              | See general                                   | See general                     |
|                          | High Density High Rise                | M-H3              | See general                                   | See general                     |
|                          | Low Profile Support Commercial        | M-X1              | See general                                   | See general                     |
|                          | Medium Profile Support Commercial     | M-X2              | See general                                   | See general                     |



**Table 5-10: Special Purpose Districts Minimum Landscape Coverage**

(The City of Calgary 2008 (May 2010 Update)-a)

| <b>CITY OF CALGARY LAND USE</b>         |                | <b>% PARCEL COVERAGE</b>   | <b>CITY OF CALGARY<br/>LAND USE BYLAW<br/>1P2007 SECTION</b> |
|---|----------------|--|--|
| <b>DISTRICT DESCRIPTION</b>             | <b>CODE(S)</b> |  |  |
| Urban Nature                            | S-UN           | 100% (natural)   | 1014(2)  |
| School, Park and<br>Community Reserve   | S-SPR          | Set-back areas   | 1030 - 1031(1)   |
| Community Service                       | S-CS           | Set-back areas   | 1038 - 1039  |
| Recreation                              | S-R            | Set-back area<br>+ 15 (parking areas<br>>5000m <sup>2</sup> )                      | 1049-1050, 1051(1),<br>1051(2)                               |
| Community Institution                   | S-CI           | 40 (with ≤30% hard<br>landscaping)<br>+ 15 (parking areas<br>>5000m <sup>2</sup> ) | 1062-1064  |
| City and Regional<br>Infrastructure     | S-CRI          | Set-back area  | 1071   |
| University Research Park                | S-URP          | Set-back area  | 1082   |
| Future Urban<br>Development             | S-FUD          | 100% (natural)   | 1014(1)  |
| Transportation and Utility<br>Corridors | S-TUC          | 100% (natural)   | 1014(1)  |

**Table 5-11: City Centre District Minimum Landscape Coverage**

(The City of Calgary 2008 (May 2010 Update)-b)

| <b>CITY OF CALGARY LAND USE</b>                   |                | <b>% PARCEL<br/>COVERAGE</b> | <b>CITY OF CALGARY<br/>LAND USE BYLAW<br/>1P2007 SECTION</b> |
|---|----------------|------------------------------|--|
| <b>DISTRICT DESCRIPTION</b>                       | <b>CODE(S)</b> |                              |  |
| Multi-Residential High Rise                       | CC-MH          | 35                           | 1131   |
| Multi-Residential High Rise<br>Support Commercial | CC-<br>MHX     | 30                           | 1141   |
| Mixed Use   | CC-X           | 30                           | 1173(1)  |
| Commercial Corridor                               | CC-COR         | Setback areas                | 1194   |

**Table 5-12: Downtown and Beltline Special District Minimum Landscape Coverage**

(The City of Calgary 2008 (May 2010 Update)-b)

|         | CITY OF CALGARY LAND USE           |         | % PARCEL COVERAGE   | CITY OF CALGARY LAND USE BYLAW 1P2007 SECTION |
|---------|------------------------------------|---------|---|---|
|         | DISTRICT DESCRIPTION               | CODE(S) |   |   |
| Special | Agricultural and Open Space        | A       | Front & Rear Yards(7.5m); Side Yard (4.5m); Min site area 8 ha(20 acres)              | 49(3)(a-d)                                    |
|         | Direct Control                     | DC      | n/a   | 50  |
|         | Public Park, School and Recreation | PE      | Yard depth = height of building face adjacent to property line (if $\geq 6\text{m}$ ) | 51(3)(a-b)                                    |
|         | Public Service                     | PS      | Yard depth = height of building face adjacent to property line (if $\geq 6\text{m}$ ) | 52(3)(a-b)                                    |
|         | University Research                | UNR     | 15m front & side yard depths  | 53(3)(a-b)                                    |
|         | Urban Reserve                      | UR      | Front Yards(7.5m); Min site area 32 ha(80 acres)                                      | 54(3)(a-c)                                    |

**Table 5-13: Downtown and Beltline District Maximum Parcel Coverage**

(Buildings, Parking Stalls, Garbage Facilities)  
 (The City of Calgary 2008 (May 2010 Update)-b)

| CITY OF CALGARY LAND USE  |                               |   | % PARCEL COVERAGE                   | CITY OF CALGARY LAND USE BYLAW 1P2007 SECTION |
|---|-------------------------------|---|-------------------------------------|---|
|   | DISTRICT DESCRIPTION          | CODE(S)   |                                     |   |
| Residential   | General Rules                 | N/A   | 45                                  | 20.1(3)(I)(i)                                 |
|   | Restricted Single Detached    | RR-1  | 40                                  | 21(3)(g)                                      |
|   | Single-Detached               | R-1   | 45                                  | 22(3)(g)                                      |
|   | Small Lot                     | RS-1, RS-2  | 60                                  | 22.1(3)(g)                                    |
|   | Narrow Lot                    | R-1A  | 45                                  | 22.2(3)(h)                                    |
|   | Low Density                   | R-2, R-2A   | 45                                  | 23(3)(g), 24(3)(g)                            |
|   | Mobile Home                   | R-MH  | 45                                  | 25(3)(a)(vii)                                 |
|   | Low Density Multi-Dwelling    | RM-1, RM-2, RM-3  | 60                                  | 26(3)(d), 27(3)(e), 28(3)(f)                  |
|   | Medium Density Multi-Dwelling | RM-4, RM-4/125, RM-4/100, RM-4/75, RM-5   | 60                                  | 29(3)(f), 30(3)(f)                            |
|   | High Density Multi-Dwelling   | RM-6  | 65                                  | 31(3)(f)                                      |
|   | High Density Multi-Dwelling   | RM-7  | 60                                  | 32(3)(f)                                      |
| Commercial  | Convenience                   | CC  | 45                                  | 34(5)(d)                                      |
|   | Local                         | C-1, C-1A   | *90                                 | 35(3)(a-f)                                    |
|   | General                       | C-2, C-2(20), C-2(16), C-2(12); C-3, C-3(38), C-3(30), C-3(27), C-3(23), C-3(20), C-3(16); C-4, C-4(38), C-4(30), C-4(27), C-4(23), C-4(20) | 60                                  | 36(5)(c)(i), 37(5)(c)(i), 38(5)(d)(i)         |
|   | Shopping Centre               | C-5, C-5/.75, C-5/.5  | *72                                 | 39(3)(d)(iv), 39(5)e)                         |
|   | Highway                       | C-6   | **55                                | 40(3)(a-c), 40(3)(f),                         |
|   | Central Business              | CM-1  | n/a                                 |   |
|   | Downtown Business             | CM-2  | n/a                                 |   |
| Industrial  | Business Park                 | I-1   | As per any industrial business park | 44(5)(d)                                      |
|   | General Light                 | I-2   | Yard area                           | 45(3)(j)                                      |
|   | Heavy                         | I-3   | Front Yard area                     | 46(5)(b)                                      |
|   | Limited Serviced              | I-4   | n/a                                 |   |
| * Based on setback over perimeter & min shopping centre area (assumed square) |                               |   |                                     |   |
| ** Based on setbacks over min frontage size (assumed square property)         |                               |   |                                     |   |

Assuming the landscaping utilized would be 100% soft surfaced (i.e. living or derived from living organisms, not formed into a structure, may include but are not limited to mulch, native grasses, plants, shrubs and trees (The City of Calgary 2008 (May 2010 Update)-a)) the general percentage of permeable groundcovers associated with the municipality's land use descriptors are used to represent the respective *Zone Factors*. In the cases where a value is not clearly stipulated, assumptions are made based on permitted use (see Table 5-14).

**Table 5-14: Adopted Minimum Landscape Coverage**

| CITY OF CALGARY LAND USE |                                    |                               | % PARCEL<br>COVERAGE | BASIS OF ASSUMED VALUE   |
|--------------------------|------------------------------------|-------------------------------|----------------------|--|
| DISTRICT DESCRIPTION     |                                    | CODE(S)                       |                      |  |
| Industrial Districts     | General                            | I-G                           | 40                   | Similar to General Commercial  |
|                          | Business                           | I-B                           | 40                   | Similar to General Commercial  |
|                          | Edge                               | I-E                           | 40                   | Similar to General Commercial  |
|                          | Commercial                         | I-C                           | 40                   | Similar to General Commercial  |
|                          | Redevelopment                      | I-R                           | 20                   | Estimate due to small properties   |
|                          | Outdoor                            | I-O                           | 90                   | Few small buildings on large properties  |
|                          | Heavy                              | I-H                           | 60                   | Estimate: many heavy industrial businesses have yards that are primarily gravel                  |
| Special Purpose District | School, Park and Community Reserve | S-SPR                         | 40                   | Similar to S-CI  |
|                          | Community Service                  | S-CS                          | 40                   | Similar to S-CI  |
|                          | Recreation                         | S-R                           | 40                   | Similar to S-CI  |
|                          | City and Regional Infrastructure   | S-CRI                         | 40                   | Similar to S-CI  |
|                          | University Research Park           | S-URP                         | 40                   | Similar to S-CI  |
| Special District         | Agricultural/Open Space            | A                             | 90                   | Large area; all areas not covered by buildings   |
|                          | Direct Control                     | DC                            | 50                   | Dependent upon use   |
|                          | Public Park, School and Recreation | PE                            | 60                   | Similar to RR-1 (to accommodate for school yards)  |
|                          | Public Service                     | PS                            | 40                   | Similar to General Commercial (based on use)   |
|                          | University Research                | UNR                           | 40                   | Similar to General Commercial (based on use)   |
|                          | Urban Reserve                      | UR                            | 90                   | Similar to A   |
| Industrial District      | Business Park                      | I-1                           | 40                   | Similar to General Commercial  |
|                          | General Light                      | I-2                           | 40                   | Similar to General Commercial  |
|                          | Heavy                              | I-3                           | 60                   | Estimate: many heavy industrial businesses have yards that are primarily gravel                  |
|                          | Limited Serviced                   | I-4                           | 90                   | Estimate: large tracts of land with minimal or no land servicing requirements, primarily storage |
| Commercial District      | Neighborhood                       | C-N1, C-N2,                   | 30                   | Similar to CC-X  |
|                          | Community                          | C-C1, C-C2                    | 30                   | Similar to CC-X  |
|                          | Corridor                           | C-COR1,<br>C-COR2,<br>C-COR3, | 30                   | Similar to CC-COR  |
|                          | Office                             | C-O                           | 30                   | Similar to CC-X  |
|                          | Regional                           | C-R1, C-R2, C-R3              | 30                   | Similar to CC-X  |
| Commercial Corridor      |                                    | CC-COR                        | 30                   | Similar to CC-X  |
| Other (including N/A)    |                                    |                               | 50                   | Select average of all codes  |

#### 5.4.2.1 Exposure Assessment

Health Canada recommends general equations to estimate contaminant dose for dermal contact, ingestion and inhalation of contaminated soil particles and ingestion of contaminated water and other sources(Health Canada 2004a), but not for dermal contact with contaminated water. Dermal exposure with contaminated water is assessed based on the EPA guidance for dermal risk assessment (USEPA 2004b) and ONLY if a potable water well is located on the subject site under assessment. The actual equations used in the PHIF are modified versions that utilize the human receptor characteristic parameters identified in the AENV Tier 1/Tier 2 Soil and Groundwater Remediation Guidelines (AENV 2008b). The major modification from the basic equation (Equation 5–3) is with the contact rate as it is medium specific. The human receptor exposure parameters required for completing the health assessment are provided in Table 5-15.

The equations used for the evaluation the exposure dose for specific pathways are as follows:

**Equation 5–4: Dermal Contact with Contaminated Soil**

$$\frac{\text{Dermal Exposure Dose}}{(\text{mg/kg-day})} = \sum_{i=1}^5 \frac{(ZF \times C_{Si}) \times (SA_H \times DL_H + SA_O \times DL_O) \times AF_{SKIN} \times EF \times ET_{1i} \times ET_{3i}}{BW}$$

where,

- i = Counter for maximum of five sites to be evaluated (subject + 4 neighboring sites)
- ZF = Zone Factor (scale factor based on subject property land-use designation & associated minimum %permeable groundcover)
- C<sub>Si</sub> = Contaminant Exceedance Concentration based on land-use and soil type remediation guideline values  
= measured – background concentration – guideline value (mg/kg)
- SA<sub>H</sub> = Receptor-specific skin surface area - hand (m<sup>2</sup>)
- SA<sub>O</sub> = Receptor-specific skin surface area - other (m<sup>2</sup>)
- DL<sub>H</sub> = Receptor-specific soil dermal loading to hand skin surface (kg/event)
- DL<sub>O</sub> = Receptor-specific soil dermal loading to other skin surface (kg/event)
- AF<sub>SKIN</sub> = Chemical-specific dermal absorption factor (unitless)
- EF = Dermal exposure frequency (events/day)
- ET<sub>1i</sub> = Land use specific exposure term  
((days/wk ÷ 7wk) X wk/yr ÷ 52)) (unitless)
- ET<sub>3i</sub> = Land use and Pathway specific exposure term for non-carcinogenic effects and lifetime exposure for carcinogenic effects (years / lifetime years) (unitless)
- BW = Receptor-specific body weight (kg)

**Equation 5–5: Inhalation of Contaminated Soil Particles**

$$\frac{\text{Inhalation Exposure}}{\text{Dose (mg/kg-day)}} = \sum_{i=1}^5 \frac{(ZF \times C_{Si}) \times (IR_S \times AF_{LUNG}) \times ET_{2i} \times ET_{1i} \times ET_{3i}}{BW}$$

where,

- i = Counter for maximum of five sites to be evaluated (subject + 4 neighbouring sites)
- ZF = Zone Factor (scale factor based on land-use designation & associated minimum % permeable groundcover)
- C<sub>Si</sub> = Contaminant Exceedance Concentration based on land-use and soil type remediation guideline values (mg/kg)  
= Measured – background concentration – guideline value
- IR<sub>S</sub> = Receptor-specific soil inhalation rate (kg/event)
- AF<sub>LUNG</sub> = Chemical specific lung absorption factor (unitless)
- ET<sub>1i</sub> = Land use specific exposure term  
((days/wk ÷ 7wk) × (wk/yr ÷ 52)) (unitless)
- ET<sub>2i</sub> = Land use specific exposure term (hr/day ÷ 24hr)
- ET<sub>3i</sub> = Land use and pathway specific exposure term for non-carcinogenic effects and lifetime exposure for carcinogenic effects (years / lifetime years) (unitless)
- BW = Receptor Specific Body Weight (kg)



**Equation 5–6: Inadvertent Ingestion of Contaminated Soil**

$$\frac{\text{Ingestion Exposure}}{\text{Dose (mg/kg – day)}} = \sum_{i=1}^5 \frac{(ZF \times C_{Si}) \times (SIR \times AF_{GUT}) \times ET_{1i} \times ET_{3i}}{BW}$$

where,

- i = Counter for maximum of five sites to be evaluated (subject + 4 neighbouring sites)
- ZF = Zone Factor (scale factor based on land-use designation & associated minimum % permeable groundcover)
- C<sub>Si</sub> = Contaminant Exceedance Concentration based on land-use and soil type remediation guideline values(mg/kg)  
= Measured – background concentration – guideline value
- SIR = Receptor-specific soil ingestion rate (kg/day)
- AF<sub>GUT</sub> = Chemical specific intestinal absorption factor (unitless)
- ET<sub>1i</sub> = Land use specific exposure term  
((days/wk ÷ 7wk) × (wk/yr ÷ 52)) (unitless)
- ET<sub>3i</sub> = Land use and pathway specific exposure term for non-carcinogenic effects and lifetime exposure for carcinogenic effects (years / lifetime years) (unitless)
- BW = Receptor Specific Body Weight (kg)

**Equation 5–7: Ingestion of Contaminated Drinking Water**

$$\frac{\text{Dermal Exposure}}{\text{Dose}(mg/kg - day)} = \sum_{i=1}^5 \frac{C_{wi} \times (WIR \times AF_{GUT}) \times ET_{1i} \times ET_{3i}}{BW}$$

where,

- i = Counter for maximum of five sites to be evaluated (subject + 4 neighbouring sites)
- $C_{wi}$  = Contaminant Exceedance Concentration in water based on land-use and soil type remediation guideline values(mg/L)  
= Measured – background concentration – guideline value
- WIR = Receptor-specific water ingestion rate (L/day)
- $AF_{GUT}$  = Chemical-specific intestinal absorption factor (unitless)
- $ET_{1i}$  = Land use specific exposure term  
((days/wk ÷ 7day/wk) × (wk/yr ÷ 52)) (unitless)
- $ET_{3i}$  = Land use and pathway specific exposure term for non-carcinogenic effects and lifetime exposure for carcinogenic effects (years / lifetime years) (unitless)
- BW = Receptor Specific Body Weight (kg)

**Equation 5–8: Dermal Contact with Contaminated Water**

$$\frac{\text{Ingestion Exposure Dose}}{\text{(mg/kg-day)}} = \sum_{p=1}^n DA_{\text{EVENT}} \times \frac{((SA_H + SA_O) \times CF_{SA}) \times AF_{\text{SKIN}} \times ET_{1i} \times ET_{3i} \times EF}{BW}$$

where,

p, n = Counter for number of contaminants identified

DA<sub>EVENT</sub> = Absorbed dose per event (mg/cm<sup>2</sup>-event)

SA<sub>H</sub> = Receptor Specific skin surface area – hand (m<sup>2</sup>)

SA<sub>O</sub> = Receptor Specific skin surface area – other (m<sup>2</sup>)

AF<sub>SKIN</sub> = Chemical specific dermal absorption factor (unitless)

CF<sub>SA</sub> = Surface Area Conversion Factor (10,000 cm<sup>2</sup>/m<sup>2</sup>)

EF = Event Frequency (1 = event/day)

ET<sub>1i</sub> = Land use specific exposure term  
((days/wk ÷ 7wk) × (wk/yr 52)) (unitless)

ET<sub>3i</sub> = Land use and pathway specific exposure term for non-carcinogenic effects and lifetime exposure for carcinogenic effects  
(years / lifetime years) (unitless)

BW = Receptor Specific Body Weight (kg)

### Equation 5–9: Dermal Absorbed Dose per Event (Organic Compounds)

If  $t_{\text{event}} \leq t^*$ , then

$$DA_{\text{EVENT}} \text{ (mg/cm}^2\text{-event)} = \sum_{i=1}^5 \left( 2 FA \times K_p \times C_w \times CF_C \sqrt{\frac{6 \tau_{\text{event}} \times t_{\text{event}}}{\pi}} \right)$$

If  $t_{\text{event}} > t^*$ , then

$$DA_{\text{EVENT}} \text{ (mg/cm}^2\text{-event)} = \sum_{i=1}^5 \left( FA \times K_p \times C_w \times CF_C \left[ \frac{\tau_{\text{event}}}{1+B} + 2 \tau_{\text{event}} \left( \frac{1+3B+3B^2}{(1+B)^2} \right) \right] \right)$$

where,

$i$  = Counter for maximum of five sites to be evaluated (subject + 4 neighboring sites)

$DA_{\text{EVENT}}$  = Absorbed dose per event (mg/cm<sup>2</sup>-event)

$FA$  = Fraction of Absorbed Water - Chemical Specific (unitless)

$K_p$  = Dermal permeability coefficient of compound in water - Chemical Specific (cm/hr)

$C_w$  = Chemical concentration in water – Site Specific (mg/L)

$CF_C$  = Concentration Conversion Factor (0.001 L/cm<sup>3</sup>)

$\tau_{\text{event}}$  = Lag time per event - Chemical specific (hr/event)

=  $0.105 \times 10^{0.0056 \times MW}$ , where MW = molecular weight (g/mol)

$t_{\text{event}}$  = Event duration (hr/event)

$B$  = Dimensionless ratio of permeability coefficient of a compound through the stratum corneum relative to viable epidermis – Chemical Specific (unitless)

=  $P \frac{\sqrt{MW}}{2.6}$ , where MW = molecular weight (g/mol)

$t^*$  = Time to reach steady state - Chemical specific (hr)

=  $2.4 \tau_{\text{event}}$  (if  $B \leq 0.6$ )

=  $6 \tau_{\text{event}} (b - \sqrt{b^2 - c^2})$  (if  $B > 0.6$ )

where,  $b = \frac{2(1+B)^2}{\pi} - c$

$c = \frac{1+3B+3B^2}{3(1+B)}$

**Equation 5–10: Dermal Absorbed Dose per Event (Inorganic Compounds)**

$$DA_{\text{EVENT}}(\text{mg}/\text{cm}^2 - \text{event}) = \sum_{i=1}^5 C_W \times CF_C \times K_p \times t_{\text{event}}$$

where,

i = Counter for maximum of five sites to be evaluated (subject + 4 neighboring sites)

$DA_{\text{EVENT}}$  = Absorbed dose per event ( $\text{mg}/\text{cm}^2$ -event)

$K_p$  = Dermal permeability coefficient of compound in water - Chemical Specific ( $\text{cm}/\text{hr}$ )

$C_W$  = Chemical concentration in water – Site Specific ( $\text{mg}/\text{L}$ )

$CF_C$  = Concentration Conversion Factor ( $0.001 \text{ L}/\text{cm}^3$ )

$t_{\text{event}}$  = Event duration ( $\text{hr}/\text{event}$ )

**Table 5-15: Human Receptor Exposure Parameters**

| PARAMETER  |   | SYMBOL          | UNIT                     | TODDLER<br>(7 MO –<br>4.5 YRS) | ADULT<br>(22+ YRS) |
|--|---|-----------------|--------------------------|--------------------------------|--------------------|
| Body Weight  |   | BW              | kg                       | 16.5                           | 70.7               |
| Air Inhalation Rate  |   | IR              | m <sup>3</sup> /d        | 9.3                            | 15.8               |
| Soil Inhalation Rate   |   | IRS             | kg/d                     | 7.10E-09                       | 1.20E-08           |
| Water Ingestion Rate   |   | WIR             | L/d                      | 0.6                            | 1.5                |
| Soil Ingestion Rate  |   | SIR             | kg/d                     | 8.0E-05                        | 2.0E-05            |
| Water Contact Rate*  |   | WCR             | hr/event                 | 1                              | 0.58               |
| Skin<br>Surface<br>Area  | Hands   | SA <sub>H</sub> | m <sup>2</sup>           | 0.043                          | 0.089              |
|  | Other   | SA <sub>O</sub> | m <sup>2</sup>           | 0.258                          | 0.25               |
| Dermal<br>Loading<br>to Skin   | Hands   | DL <sub>H</sub> | kg/m <sup>2</sup> -event | 0.001                          | 0.001              |
|  | Other   | DL <sub>O</sub> | kg/m <sup>2</sup> -event | 0.0001                         | 0.0001             |
| Exposure Frequency   |   | EF              | events/day               | 1                              | 1                  |
| Exposure Term  | Agricultural, Residential/Parkland                                  | ET              | -                        | 1                              | 1                  |
|  | Commercial, Industrial  | ET              | -                        | 0.2747                         | 0.2747             |
|  | Agricultural, Residential/Parkland<br>((days/wk ÷ 7wk)x wk/yr ÷ 52) | ET <sub>1</sub> | -                        | 1                              | 1                  |
|  | Commercial, Industrial<br>((days/wk ÷ 7wk)x wk/yr ÷ 52)             | ET <sub>1</sub> | -                        | 0.6593                         | 0.6593             |
|  | Agricultural, Residential/Parkland<br>(hr/day ÷ 24hr)               | ET <sub>2</sub> | -                        | 1                              | 1                  |
|  | Commercial, Industrial<br>(hr/day ÷ 24hr)                           | ET <sub>2</sub> | -                        | 0.4167                         | 0.4167             |
| **Life<br>Exposure <sub>c</sub>  | Non-carcinogenic (threshold)<br>contaminant exposure                | ET <sub>3</sub> | -                        | 0.0600                         | 0.7467             |
|  | Carcinogenic (non-threshold)<br>contaminant exposure                | ET <sub>3</sub> | -                        |                                | 1.0000             |
| * Reasonable Maximum Exposure Exhibit 3-2, p.3-8, (USEPA 2004b)                              |   |                 |                          |                                |                    |
| ** Based on years exposure over entire life range (Toddler = 4.5/75; Adult = 56/75 or 75/75) |   |                 |                          |                                |                    |
| Table 4, p.13(Health Canada 2004a)   |   |                 |                          |                                |                    |

(AENV 2008b; c)

#### 5.4.2.1.1 Risk Characterization

Once the exposure doses are estimated, the next step is characterization of the risks associated with exposure to carcinogen and non-carcinogens. For substances that present risks other than cancer, a Hazard Quotient (HQ) is derived for each substance and pathway. The HQ is a ratio of the estimated exposure to the Tolerable Daily Intake (TDI) or Reference Dose (RfD) associated with a particular substance and pathway. The TDI (RfD) represents the maximum amount of substance (generally in milligrams) that an individual can be exposed to on a daily basis, per kilogram weight without causing adverse effects. Note that the same TDI/RfD is recommended for the ingestion (oral) and dermal pathways (CCME 2006; USEPA 1989). Since simultaneous exposure to multiple chemicals must be accounted for, the individual quotients are summed to provide an overall HQ. The assumption being made in this analysis is that all of the chemicals under assessment have similar target organs, effects, and/or mechanisms of action. The number obtained does not represent a probability of an individual suffering an adverse effect but only indicates a level of concern.

For substances that are deemed carcinogenic, the exposure that has been estimated over the entire lifetime of the individual (i.e. 70 years) is multiplied by the appropriate Slope Factor (SF) or Unit Risk (UR) for the substance to provide a Carcinogenic Risk value. As with the HQ, the same SF or UR is used for the ingestion (oral) and dermal exposure pathways. Since simultaneous exposure to multiple chemicals must be accounted for, the individual risks are summed to provide an overall Risk. The assumption being made is that all of the chemical under assessment have similar target organs, effects, and/or mechanisms of action. The final value obtained from this calculation provides an indication of the incremental probability of an individual developing cancer over a lifetime as a result of exposure to potential carcinogens.

The TDI/RfD and SF (UR) values are obtained from controlled epidemiologic investigations, clinical studies, and experimental animal studies. The majority of test results are based on animals and extrapolated to humans through the use of uncertainty factors. If adequate human data is available, this information is used. The TDI (or RfD) represents the toxicity value for evaluating non-carcinogenic effects resulting from exposure to certain chemicals. The SF (or

UR) is a toxicity value that represents the likelihood that a substance is a human carcinogen and quantifies the relationship between dose and response. As the dose-response relationship is linear only at the lower end of the dose-response curve, it is assumed that the concentration of the contaminant at the site is relatively low compared to test concentrations and thus will lie in the lower region and the risk will be directly related to intake. (CCME 2006; USEPA 1989)

The values used for TDI/RfD and SF/UR were obtained from the Alberta Tier 1/Tier 2 Soil and Water quality guidelines. The equations for HQ and Potential Carcinogenic Risk (PCR) are presented below.

**Equation 5–11: Unit Hazard Quotient (HQ<sub>unit</sub>)**

$$HQ_{\text{UNIT}} = \sum_{j=1}^2 \sum_{i=1}^n \left[ \frac{(ED_{\text{ORAL}} + ED_{\text{DERMAL}})}{TDI_0} + \frac{(ED_{\text{INHALATION}})}{TDI_1} \right]$$

where,

HQ<sub>UNIT</sub> = Level of Concern for SITE under assessment (Subject, neighboring)  
(unitless)

i = Counter for number of contaminants

j = Contaminated Media count (soil & groundwater)

ED<sub>ORAL</sub> = Estimated Oral Exposure Dose (mg/kg-day)

ED<sub>DERMAL</sub> = Estimated Dermal Exposure Dose (mg/kg-day)

ED<sub>INHAL</sub> = Estimated Inhalation Exposure Dose (mg/kg-day)

TDI<sub>0</sub> = Oral Reference Dose (mg/kg-day)

TDI<sub>1</sub> = Inhalation Reference Dose (mg/kg-day)

This equation is applied to each of the 5 sites (subject and four adjacent properties) and prorated as describe previously to obtain an overall HQ.



**Equation 5–12: Hazard Quotient (HQ)**

$$HQ = (0.6 \times HQ_{\text{SUBJECT SITE}}) + \sum_{i=1}^4 (0.1 \times HQ_{\text{ADJACENT SITE}})$$

where,

i = Adjacent site (1 = north site, 2 = west site; 3 = south site; 4 = east site)

**Equation 5–13: Unit Potential Carcinogenic Risk (PCR)**

$$PCR_{\text{UNIT}} = \sum_{j=1}^2 \sum_{i=1}^n [(ED_{\text{ORAL}} + ED_{\text{DERMAL}}) \times SF_O + (ED_{\text{INHALATION}}) \times SF_I]$$

where,

$PCR_{\text{UNIT}}$  = Probability of an individual developing cancer for SITE under assessment (unitless)

i = Counter for number of contaminants

j = Contaminated Media count (soil & groundwater)

$ED_{\text{ORAL}}$  = Estimated Oral Exposure Dose (mg/kg-day)

$ED_{\text{DERMAL}}$  = Estimated Dermal Exposure Dose (mg/kg-day)

$ED_{\text{INHAL}}$  = Estimated Inhalation Exposure Dose (mg/kg-day)

$SF_O$  = Oral slope factor ((mg/kg-day)<sup>-1</sup>)

$SF_I$  = Inhalation slope factor ((mg/kg-day)<sup>-1</sup>)

Similarly, this equation is applied to each of the 5 sites (subject and four adjacent properties) and prorated as describe previously to obtain an overall PCR.

**Equation 5–14: Overall Potential Carcinogenic Risk**

$$PCR_{\text{OVERALL}} = (0.6 \times PCR_{\text{SUBJECT SITE}}) + \sum_{i=1}^4 (0.1 \times PCR_{\text{ADJACENT SITE}})$$

where,

i = adjacent sites (1 = north site, 2 = west site; 3 = south site; 4 = east site)

#### 5.4.2.1.2 PHIF Evaluation

The overall potential carcinogenic and non-carcinogenic (HQ) values obtained represent risk in a different manner and their interpretation must be dealt with separately; the decision maker must decide which of the values will take precedence during their evaluation of the data. As they are both unitless values, a simple method has been developed to transform them into numerical quantities on a similar scale so that they can be combined into a single numerical value that represents the potential human impact posed by a contaminated site.

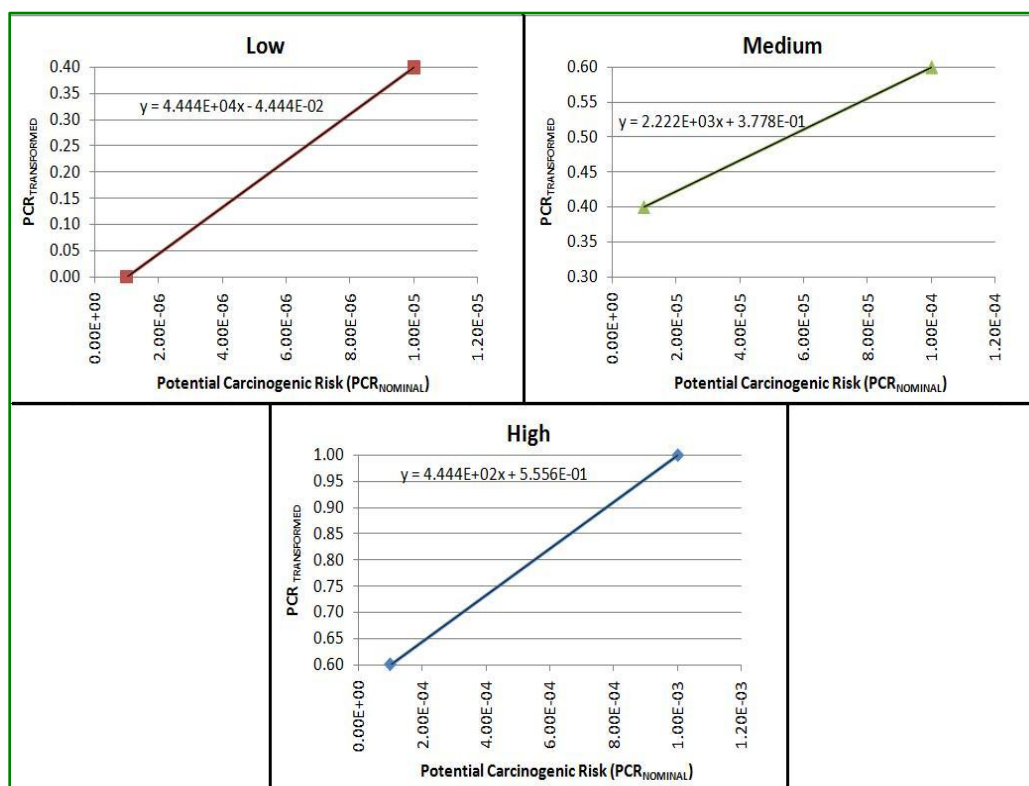
Once the overall potential carcinogenic and non-carcinogenic risk estimates are completed these numbers are transformed into a value between 0.0 and 1.0 corresponding to one of three *Level of Concern* categories through the use of linear transformation equations.

For the Potential Carcinogenic Risk (PCR), the transformation equations are derived based on the value ranges associated with the designated *Level of Concern* and the respective PCR ranges. Guidance documents for Canada, and Alberta, indicate that the total cancer risks for simultaneous exposure to multiple chemicals of concern are to be deemed “essentially negligible” when the  $PCR \leq 1 \times 10^{-5}$ . Prior to Health Canada issuing its “essentially zero” risk level, the USEPA endorsed value of  $1 \times 10^{-6}$  (1-in-1-million) was more commonly accepted and widely used (Health Canada 2004a; USEPA 1989). According to, Health Canada “negligible” carcinogenic risk values lie between  $10^{-5}$  and  $10^{-6}$  but are restricted to exposures

via drinking water. Thus, as these two values represent the threshold for concern the  $1 \times 10^{-6}$  value is used as the base point of the 'Low' *Level of Concern* category and the Health Canada value is used the upper bound of the same level of concern. The *Level of Concern* boundaries for the Medium and High categories encompass the same ten-fold range, with an additional range for High category wherein any PCR value greater than 1 in 1000 ( $1 \times 10^{-3}$ ) is considered extreme and equated to the maximum attainable transformed value, 1.0. Graphical representation of the ranges from each level provides the linear equations for transformation. These are presented in Figure 5—3 and summarized in Table 5-16.

**Table 5-16: PCR Transformation Equations**

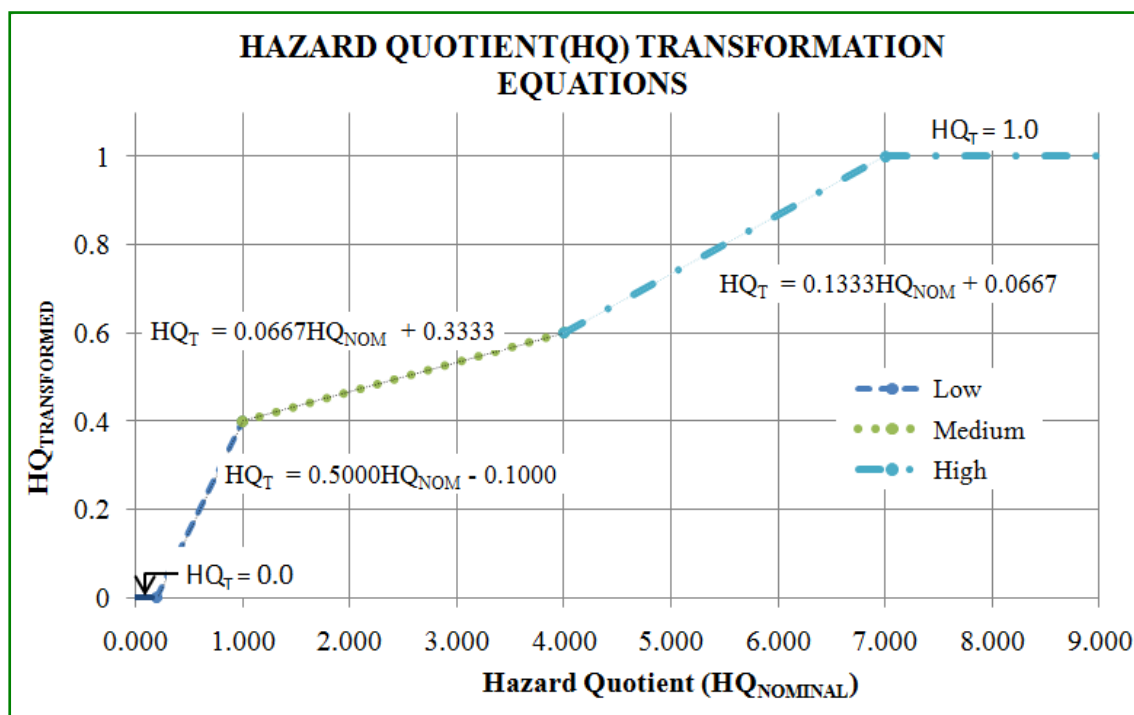
| LEVEL OF CONCERN | VALUE RANGE           | PCR <sub>NOMINAL</sub>                      | PCR <sub>TRANSFORMED</sub>  |
|------------------|-----------------------|---|---|
| Low              | $0.0 \leq x \leq 0.4$ | $\text{PCR} < 1\text{E-}6$                  | $\text{PCR}_T = 0.0000$   |
|                  |                       | $1\text{E-}6 \leq \text{PCR} < 1\text{E-}5$ | $\text{PCR}_T = (4.4444\text{E+}04) \text{PCR}_{\text{NOM}} - 0.0444$ |
| Medium           | $0.4 < x \leq 0.6$    | $1\text{E-}5 \leq \text{PCR} < 1\text{E-}4$ | $\text{PCR}_T = (2.2222\text{E+}03) \text{PCR}_{\text{NOM}} + 0.3778$ |
| High             | $0.6 < x \leq 1.0$    | $1\text{E-}4 \leq \text{PCR} < 1\text{E-}3$ | $\text{PCR}_T = (4.4444\text{E+}02) \text{PCR}_{\text{NOM}} + 0.5556$ |
|                  |                       | $1\text{E-}3 \leq \text{PCR}$               | $\text{PCR}_T = 1.0000$   |



**Figure 5—3: PCR Transformation Graphs**

For the non-carcinogenic risk levels (Hazard Quotient, HQ) the transformation equations were again derived based on the value ranges associated with the designated level of risk and the respective HQ ranges. As the HQ is a ratio of the exposure level to the reference dose, the higher the level above unity, the greater the level of concern. When dealing with multiple chemical exposures, however, the HQ can exceed unity even when no single chemical exposure or no single exposure pathway exceeds unity and thus the boundaries can be difficult to define (Health Canada 2004a; USEPA 1989). According to Health Canada, exposures associated with a  $HQ \leq 0.2$  are deemed to be negligible (Health Canada 2004a). While this provides a lower bound, no upper bound value is given. The USEPA does provide guidance indicating that for HQ values  $\geq 1.0$  a concern for potential non-cancer health effects may exist. When working with multiple exposures it is recommended that the hazard indices be segregated by effect and mechanism of action. (USEPA 1989) This procedure is both complex and time consuming and therefore, for

the purpose of this MODM any HQ value less than Health Canada “zero” threshold of 0.2 is deemed negligible and any value greater than 1.0 will indicate the point of concern. These two (2) values form the boundaries for the ‘Low’ Level of Concern. For the ‘Medium’ and ‘High’ Level of Concern categories, an HQ contribution of 1.0(maximum) is assumed for each exposure pathway making each nominal value range equal to 3.0. This is based on the fact that three exposure pathways (ingestion, inhalation, dermal) are always accounted for with the soil exposure, and water exposure routes are dependent upon the presence of a potable water well on site (i.e. treated water is not supplied by the municipality). Since the sites under investigation are located within Municipality’s limits the majority would be serviced by treated water unless the sites are at the boundaries and are being evaluated for city expansion. Thus, the Level of Concern categories identified for HQ component of the PHIF with their respective boundaries and transformation equations are provided in Figure 5—4 and Table 5-17.



**Figure 5—4: HQ Transformation Graphs**

**Table 5-17: HQ Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | HQ <sub>NOMINAL</sub>     | HQ <sub>TRANSFORMED</sub>               |
|------------------|-----------------------|---------------------------|---|
| Low              | $0.0 \leq x \leq 0.4$ | $HQ_{NOM} < 0.2$          | $HQ_T = 0.0$                            |
|                  |                       | $0.2 \leq HQ_{NOM} < 1.0$ | $HQ_T = (0.5000) HQ_{NOM} - 0.1000$     |
| Medium           | $0.4 < x \leq 0.6$    | $1.0 \leq HQ_{NOM} < 4.0$ | $HQ_T = (6.6667E-02) HQ_{NOM} + 0.3333$ |
| High             | $0.6 < x \leq 1.0$    | $4.0 \leq HQ_{NOM} < 7.0$ | $HQ_T = (0.1333)HQ_{NOM} + 0.0667$      |
|                  |                       | $7.0 \leq HQ_{NOM}$       | $HQ_T = 1.0$                            |

The PCR and HQ are considered to be equal contributors to the final PHIF values as represented in the following equation:

**Equation 5–15: Potential Human Impact Factor, PHIF**

$$PHIF = \frac{PCR_{TRANSFORMED} + HQ_{TRANSFORMED}}{2}$$

where,

PCR<sub>TRANSFORMED</sub> = Potential Carcinogenic Risk value transformed into a numerical value between 0.0 and 1.0 indicating level of concern

HQ<sub>TRANSFORMED</sub> = Hazard Quotient (Potential Carcinogenic Risk) value transformed into a numerical value between 0.0 and 1.0 indicating level of concern

### ***5.4.3 Potential Ecological Impact Factor (PEIF)***

Ecological risk assessment is an interdisciplinary field that includes environmental toxicology, ecology, and environmental chemistry which encompasses processes that can influence the properties of a contaminant and its transformation products (Lee and Jones 1981; USEPA 1997a).

While many detailed guidelines for human health risk assessment (HHRA) have been established (CCME 2006; CEARC 1992; Davies 1992; Health Canada 2004a; b; Loney et al. 2007; USEPA 1989; 2004b), the same has not occurred for ecological risk assessment. Conceptual guidance documents have been developed, but do not provide a recommended step-by-step process which can be easily followed thereby leaving the direction of the assessment solely to the discretion of the risk assessor/site manager (Environment Canada 1994; USEPA 1997a; 1998).

The ecological risk assessment paradigm, while not strictly defined, has the same basic structure found in the human health assessment paradigm. That is,

1. Identify basic site characteristics (geology; hydrology; presence and location of surface water bodies, populations on or near the site, population activity patterns, site usage(zoning))
2. Identify exposure
3. Quantify the relationship between exposure and effects, and
4. Estimate risk

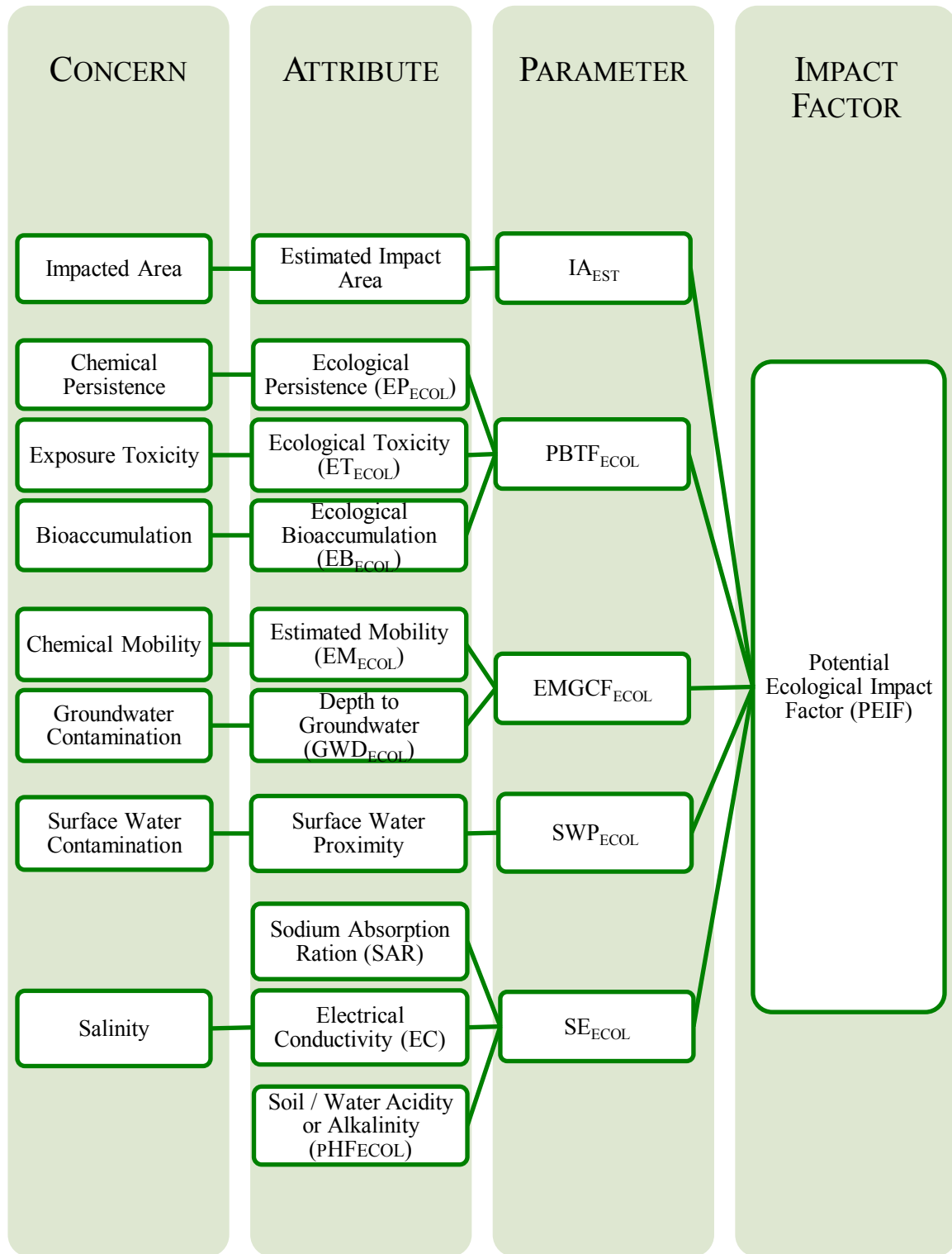
The derivation of the PEIF is based on addressing several concerns than can have a negative impact on the environment:

- Impacted Area
- Chemical Persistence
- Exposure Toxicity
- Bioaccumulation

- Chemical mobility
- Groundwater Contamination
- Surface Water Contamination
- Salinity
- pH

Each of these concerns have been translated into specific attributes, which have been combined and parameterized based on their integral components (Figure 5—5).





**Figure 5—5: Potential Ecological Impact Factor Assessment**

Evaluation of each of the parameters involves their assessment and subsequent transformation from raw values into respective “Levels of Concern”. As with the PHIF, the final PEIF will be an average of the available transformed values.

**Equation 5–16: Potential Ecological Impact Factor Level of Concern, *PEIF***

$$PEIF = \frac{IA_{EST} + PBTF_{ECOL} + EMGCF_{ECOL} + SWP_{ECOL} + SE_{ECOL}}{N}$$

where,

- N = Number of attributes to be considered (max = 5)
- IA<sub>EST</sub> = Estimated Impact Area
- PBTF<sub>ECOL</sub> = Persistence Bioaccumulation Toxicity Factor
- EMGCF<sub>ECOL</sub> = Estimated Mobility & Groundwater Contamination Factor
- SWP<sub>ECOL</sub> = Surface Water Proximity Factor
- SE<sub>ECOL</sub> = Salinity Effect

#### 5.4.3.1 Estimated Impact Area Attribute (IA<sub>EST</sub>) Assessment

The larger the area impacted by the contaminants, the greater the potential for ecological effect to occur. The area of impact may be different than the actual area of the site. For example, a service station on a section of a commercial strip-mall or larger shopping mall. The service station occupies only a small portion of the parcel, and thus using the entire surface area of the parcel will result in an overestimation of the area impacted. Thus, impact area is estimated based on the area of sampling performed during the Phase II Risk Assessment process. These values are then transformed into “Levels of Concern” via linear transformation equations based on the low, medium and high classification developed for the Level 1 MODM. It should be noted, that the lowest nominal area accounted for at the lowest level of concern is 202m<sup>2</sup> (0.05 acres), which is the area criteria for further investigation of the site based on Rule #1 of the Level 1 MODM (i.e. IF the area is less than 0.05 acres (202m<sup>2</sup>) THEN Class 2I). In

order to determine the remaining boundaries for the Levels of Concern, a review of the possible area ranges that may be encountered during the site evaluation process was performed (Table 5-18). Outlier reference values were determined as described in Equation 4-17 for the available relevant area ranges (i.e. area  $\geq 202\text{m}^2$ ).

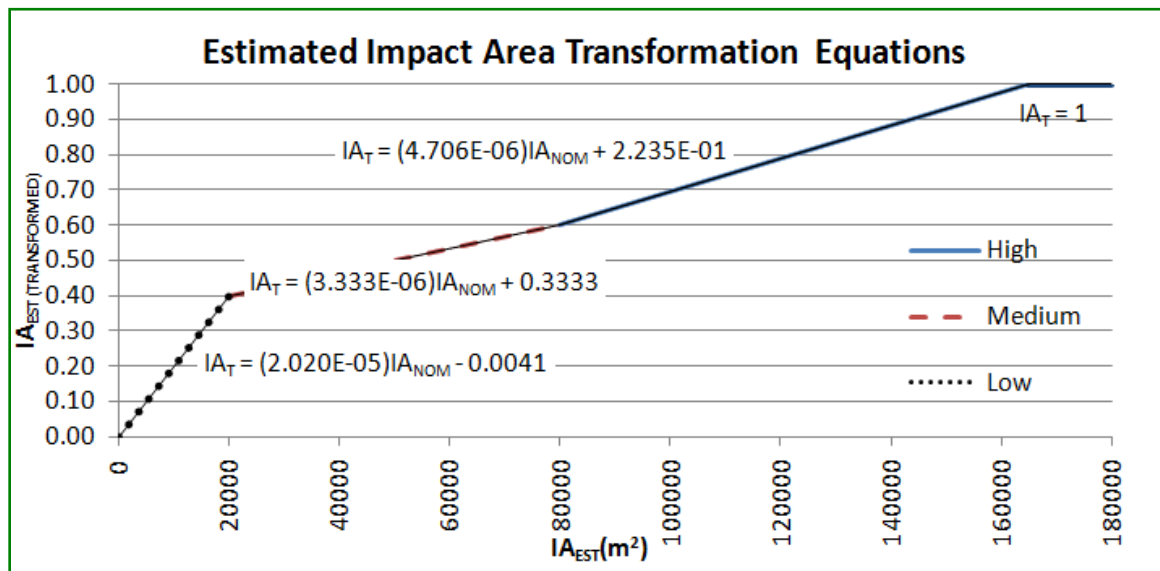
**Table 5-18: Area Outlier Review**

|                               |              | VALUE RANGE     | MEAN   | STANDARD DEVIATION | OUTLIER REFERENCE VALUE |
|-------------------------------|--------------|-----------------|--------|--------------------|-------------------------|
| ACTUAL AREA (M <sup>2</sup> ) | Level 1 Data | 211 – 1,016,073 | 13,488 | 64,300             | 142,100                 |
|                               | Level 3 Data | 286 – 308,552   | 30,307 | 66,128             | 162,562                 |
| IMPACT AREA (M <sup>2</sup> ) | Level 3 Data | 286 – 302,175   | 20,993 | 50,697             | 122,388                 |

The mean, standard deviation and outlier reference values for the Level 3 Test Data were used as guides for developing the boundaries of the  $IA_{EST}$  transformation equations provided in Table 5-18 and Table 5-19. That is, the boundaries for the *Low Level of Concern* were based on the minimum acceptable area for assessment ( $202\text{m}^2$ ) and an approximate mean impact area value ( $20,000\text{ m}^2$ ); the middle boundary used a span equal to approximately the average of one standard deviation ( $60,000\text{m}^2$ ) for the Level 3 data; and the uppermost boundary of the *High Level of Concern* was approximately the outlier reference value for the actual area ( $165,000\text{ m}^2$ ).

**Table 5-19: Estimated Impact Area Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | IMPACT AREA <sub>NOMINAL</sub> (m <sup>2</sup> ) | IMPACT AREA <sub>TRANSFORMED</sub>       |
|------------------|-----------------------|--|--|
| Low              | $0.0 \leq x \leq 0.4$ | $IA_{NOM} < 202$                                 | $IA_{EST} = 0.0$                         |
|                  |                       | $202 \leq IA_{NOM} < 20000$                      | $IA_{EST} = (2.020E-5)IA_{NOM} - 0.0041$ |
| Medium           | $0.4 \leq x \leq 0.6$ | $20000 \leq IA_{NOM} < 80000$                    | $IA_{EST} = (3.333E-6)IA_{NOM} + 0.3333$ |
| High             | $0.6 \leq x \leq 1.0$ | $80000 \leq IA_{NOM} < 165000$                   | $IA_{EST} = (4.706E-6)IA_{NOM} + 0.2235$ |
|                  |                       | $165000 \leq IA_{NOM}$                           | $IA_{EST} = 1.0$                         |

**Figure 5—6: Estimated Impact Area (IA<sub>EST</sub>) Transformation Equations**

#### 5.4.3.2 Estimated Persistence, Bioaccumulation & Toxicity Factor (PBTF)

In March 2000 modifications to the Canadian Environmental Protection and Enhancement Act were made to include regulations regarding the categorization of the persistence and bioaccumulative tendencies of substances and in 2003 Environment Canada published a Guidance manual to explain the scientific categorization for persistence, bioaccumulation and inherent toxicity to non-human organisms. (Environment Canada 2003; Government of Canada 2000) The PBTF factor follows these guidance documents and expands where required to provide a comprehensive estimation of the fate of chemicals in the environment and the effects on the ecology of the site. It is derived by averaging the estimated effects of its integral components; Ecological Persistence ( $EP_{ECOL}$ ), Ecological Bioaccumulation ( $EB_{ECOL}$ ) and Ecological Toxicity ( $ET_{ECOL}$ ).

#### Equation 5–17: Estimated Persistence, Bioaccumulation & Toxicity Factor, *PBTF*

$$PBTF = \frac{EP_{ECOL} + EB_{ECOL} + ET_{ECOL}}{3}$$

where,

$EP_{ECOL}$  = Estimated Ecological Persistence (unitless)

$EB_{ECOL}$  = Estimated Ecological Bioaccumulation (unitless)

$ET_{ECOL}$  = Estimated Ecological Toxicity (unitless)

##### 5.4.3.2.1 Estimated Ecological Persistence ( $EP_{ECOL}$ )

Persistence is defined as the length of time a substance remains in the environmental medium. The chemical property generally associated with this parameter is half-life. Half-life is the time required for the concentration of substance to be reduced by half of its original amount through transformation processes in a medium (Government of

Canada 2000); the longer the half-life, the more persistent the substance. Categorization of half-life criteria, based on the relevant media, is provided by the Canada's Priorities for Assessment (Environment Canada 2006a) and summarized in the following table:

**Table 5-20: Persistence Criteria**

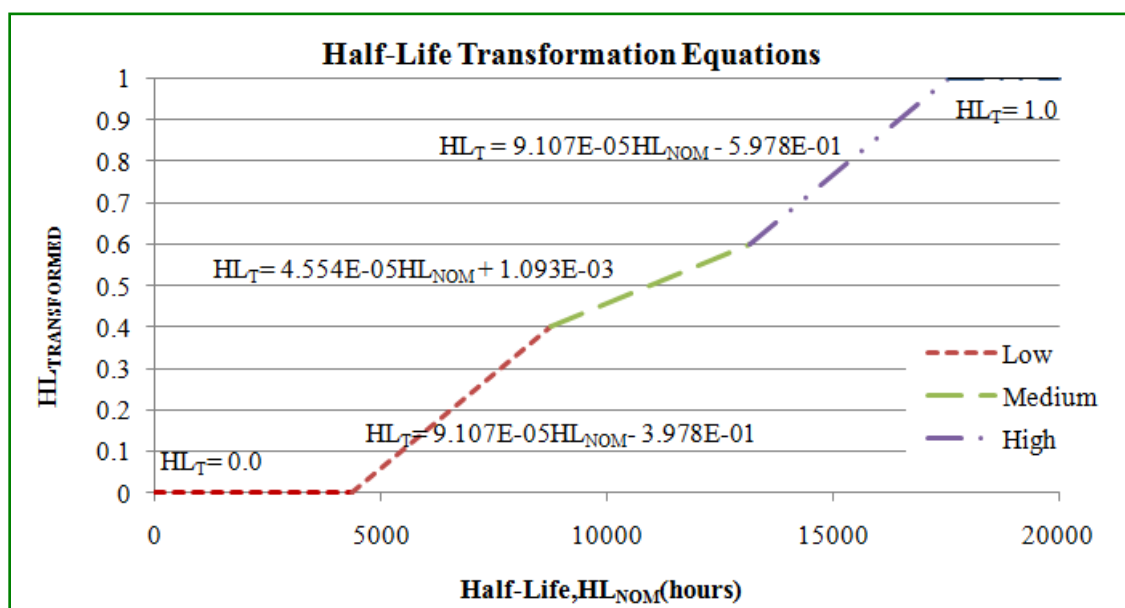
| MEDIUM   | HALF-LIFE  |             |
|----------|------------|-------------|
|          | (DAYS)     | (HOURS)     |
| Air      | $\geq 2$   | $\geq 48$   |
| Water    | $\geq 182$ | $\geq 4368$ |
| Sediment | $\geq 365$ | $\geq 8760$ |
| Soil     | $\geq 182$ | $\geq 4368$ |

In order to evaluate the  $EP_{ECOL}$ , the half-life of each substance identified as “in exceedance” in the samples analyzed will be assigned a Level of Concern value through the use of linear transformation equations. The samples collected for analysis in Phase II Environmental Site Assessments were from two media sources: soil and groundwater. Since the half-life criteria values are the same for water and soil the same transformation equations can be used to assign the Levels of Concern for each substance. The threshold value of 182 days (4368 hours) was selected as the baseline for the “low” *Level of Concern* below which half-life is considered negligible. As the half-life values for the chemicals identified through the Phase II ESA reports range from 2.5 to 672000 hours in groundwater and from 16 to 51360 hours in soil, the selection of the remaining boundaries are subject to professional judgment. Therefore, each of the boundaries values assigned to the *Level of Concern* ranges in Table 5-21 were based on a consistent time interval between the soil/water and sediment reported half-lives (i.e.  $8760 - 4368 = 4392$  hours). Any half-life greater than three (3) time intervals are considered to be extremely high and carry a transformed value of 1.0. The transformation equations were obtained through graphical means (Figure 5—7).

**Table 5-21: Half-Life Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | HALF-LIFE <sub>NOMINAL</sub> (HOURS) | HALF-LIFE <sub>TRANSFORMED</sub>      |
|------------------|-----------------------|--------------------------------------|---------------------------------------|
| Low              | $0.0 \leq x \leq 0.4$ | $HL_{NOM} < 4368$                    | $HL_T = 0.0$                          |
|                  |                       | $4368 \leq HL_{NOM} < 8760$          | $HL_T = (9.107E-05)HL_{NOM} - 0.3978$ |
| Medium           | $0.4 \leq x \leq 0.6$ | $8760 \leq HL_{NOM} < 13152$         | $HL_T = (4.554E-05)HL_{NOM} + 0.001$  |
| High             | $0.6 \leq x \leq 1.0$ | $13152 \leq HL_{NOM} < 17544$        | $HL_T = (9.107E-05)HL_{NOM} - 0.5978$ |
|                  |                       | $17544 \leq HL_{NOM}$                | $HL_T = 1.0$                          |

Based on the above transformation equations, the chemical specific Level of Concern is prorated based on the proportion of that specific chemical with respect to the total amount of substances detected on-site ( $CSF_{MEDIUM}$ ). Each chemical will have a given level of concern and contribution that when tallied will provide the estimated overall chemical persistence for a given site. The equations for chemical specific fraction ( $CSF_{MEDIUM}$ ) and  $EP_{ECOL}$  are provided below (Equation 5–18 & Equation 5–19).

**Figure 5—7: Half-Life Transformation Equations**

**Equation 5–18: Chemical Specific Fraction, CSF**

$$CSF_{MEDIUM} = \frac{[(0.6 \times C_{SUBJECT}) + \sum_{i=1}^4 0.1 \times C_{NEIGHBOR}]}{\sum_{j=1}^n [(0.6 \times C_{SUBJECT}) + \sum_{i=1}^4 (0.1 \times C_{NEIGHBOR})]}$$

where,

- CSF = Chemical Specific Fraction in given medium (soil, groundwater)
- $i$  = Number of neighboring properties (North, East, South, West)
- $j$  = Number of contaminants identified (max = n)
- $C_{SUBJECT}$  = Contaminant Exceedance Concentration based on land-use and soil type remediation guideline values (mg/kg soil, mg/L water)  
(= measured – background concentration – guideline value)
- $C_{NEIGHBOR}$  = Contaminant Exceedance Concentration based on land-use and soil type remediation guideline values (mg/kg soil, mg/L water) for neighboring property  
(= measured – background concentration – guideline value)

**Equation 5–19: Estimated Ecological Persistence,  $EP_{ECOL}$** 

$$EP_{ECOL} = \sum_{j=1}^2 \sum_{i=1}^n (HL_{TH} \times CSF_i)$$

where,

- $EP_{ECOL}$  = Chemical Specific Estimated Ecological Toxicity (mg/day)
- $HL_T$  = Chemical Specific Transformed Half-Life (Level of Concern)
- CSF = Chemical Specific Fraction in given medium (soil, groundwater)
- $i$  = Number of identified contaminants in given medium (soil, groundwater)
- $j$  = Number of mediums (= 2, soil & groundwater)



#### 5.4.3.2.2 Estimated Ecological Toxicity (ET<sub>ECOL</sub>)

Evaluation of the anthropogenic ecological effects involves the examination of contaminant fate and transport mechanics, the mechanisms of ecotoxicity associated with the contaminants present and the receptors that could be affected. The USEPA identifies the ecological receptors as the most distinct units of ecology and it is the attributes of these organisms that require protection(USEPA 1998). The use of specific organisms as endpoints does not indicate that each individual is protected but that a level of biological organization is. In order to identify the all the organisms at are at risk and then select the most susceptible to be representative of the whole would involve an in-depth examination of each site, the contaminants present, the chemical of concern and the toxicity data available for the specific receptor and COC. (USEPA 1997a) When evaluating a large number of properties, as in the case of a large Municipality, this form of detailed investigation would be extremely costly and most likely beyond the budgetary constraints of the environmental management department. In order to reduce the initial costs, a simplified investigation and evaluation is proposed. In terms of the receptor, Alberta Environment has selected a small mammal (meadow vole) for the derivation of its Soil and Groundwater Remediation Guidelines. The meadow vole was selected based on the premise that small animals are typically maximally exposed to contaminants and thus would be protective for the majority of wildlife species. The exposure parameters provided for the meadow vole also indicate the pathways of concern to be evaluated, namely ingestion of soil and water. These are provided in the following table: (AENV 2008b; c) . Life expectancy of the meadow vole is generally less than 1 year due to predator-prey relationships (Unknown 1983).

**Table 5-22: Meadow Vole Exposure Parameters**

| PARAMETER            | SYMBOL | UNIT | VALUE    |
|----------------------|--------|------|----------|
| Body Weight          | BW     | kg   | 0.017    |
| Soil Ingestion Rate  | SIR    | kg/d | 0.000058 |
| Water Ingestion Rate | WIR    | L/d  | 0.00357  |
| Life Expectancy      | LE     | Days | 154      |

The  $ET_{ECOL}$  is derived by a combination of receptor exposure parameters, medium-specific chemical-specific exceedance concentration and the inherent chemical specific toxicity to non-human receptors. The USEPA recommends the use of a chronic endpoint, the NOAEL (no-observable adverse effect concentration level) as the baseline for screening eco-toxicity exposures at Superfund remedial sites as exposures are presumed to be long-term(USEPA 1997a). Environment Canada, however, recommends the use of acute toxicity studies over chronic studies due to the availability of acute endpoints for a large number of substances (Environment Canada 2003; 2006a). Thus, for the purposes of this project, the formula derived will follow Environment Canada's recommendations and use the following acute endpoints:

- *LD50*: The amount of a material, given in a single dose, which causes the death of 50% (one half) of a group of test animals.
- *LC50*: The concentration of a chemical in air, given in a single dose, that causes the death of 50% (one half) of a group of test animals. In environmental studies it can also mean the concentration of a chemical in water
- *TDLo*: The lowest reported dose causing lethality
- *TCLo*: The lowest reported dose causing a toxic effect

The acute toxicity values listed above, are available through the Canadian Centre for Occupational Health and Safety RTECS database (CCOHS 199-). The closest data available that could be justified in applying to the meadow vole were those from tests

involving mice and rats. Data for the mice will be selectively used with the exception of incomplete data wherein the rat data will be substituted. Furthermore, LC50 and LD50 will be the primary choice for data, but reference to the TDLo or TCLo will occur in the absence of the primary endpoints.

In determining the parameters required for estimating ecological exposure, the following assumptions have been made:

- i. Home ranges for terrestrial animals can be substantial and exposure to contaminants will be based on the quality of the land/water encompassed by this range. In order to ensure that the ecological risks are not underestimated, the smallest area used by the indicator species should be assumed. Thus, for the purpose of this investigation, the home range for the ecological receptor selected (meadow vole) will be limited to the subject property under evaluation.
- ii. All exposure evaluations will be based on the same generic property use designations identified for the human exposure routes and in the same prorated quantities (i.e. 60% subject property, 10% each for the neighboring property zone(s))
- iii. All exceedance chemicals identified will be assumed to be
- iv. Equally distributed throughout the area of investigation
- v. 100% available in the diet in the same quantities as identified in the samples analyzed
- vi. 100% bioavailable (i.e. will be maximally absorbed)
- vii. Contaminant concentrations in groundwater will be considered to be equivalent to surface soil pore water concentrations for the purpose of water ingestion.
- viii. The most sensitive life stage for the indicator species is considered to extend over the acute exposure period.
- ix. For acute testing, the exposure period is generally “**one oral dose**” (CCOHS 2005). The dosage scenario depicted for the LD50 or TDLo is a single large dose

wherein a toxic effect occurs. When dealing with a meadow vole, the quantity consumed would be extremely small and thus for the purposes of the toxicity assessment the exposure over a lifetime (generally 154 days) will be considered equivalent to a single oral dose.

- x. The daily amount of contaminated media ingested by the receptor will be considered to be equivalent to “one oral dose”.

The Estimated Ecological Toxicity is evaluated through a multi-step process:

Step 1: Determine the actual quantity (acute dose) of the chemical that would have a toxic effect on the receptor. The acute dose represents the total amount of substance that will cause a toxic effect for all pathways. As the LD50 has units of mg/kg body weight, the Estimated Receptor Acute Dosage is based on the receptors’ body weight and the appropriate acute endpoint, LD50 or TDLo (Equation 5–20).

**Equation 5–20: Estimated Receptor Acute Dosage,  $RAD_{ECOL}$**

$$RAD_{SOIL} = AE \times BW_{RECEPTOR}$$

where,

$RAD_{ECOL}$  = Receptor Acute Dosage (mg/dose)

$BW_{RECEPTOR}$  = Receptor Body Weight (Meadow vole = 0.017 kg)

AE = Chemical and Pathway Specific Acute Endpoint LD50 or TDLo, (mg/kg<sub>BW</sub>-dose)

Step 2: This step involves the estimation of the amount of specific chemical (dose) the receptor would be exposed to through ingestion of contaminated media,  $RAE_{SOIL}$  and  $RAE_{WATER}$ . It is evaluated separately for soil and groundwater exposure and is a combination of the media ingestion rate and prorated chemical exceedance concentration.

**Equation 5–21: Estimated Receptor Acute Exposure,  $RAE_{SOIL}$  and  $RAE_{WATER}$** 

$$RAE_{MEDIUM} = IR_{RECEPTOR} \times \left[ (0.6 \times C_{SUBJECT}) + \sum_{i=1}^4 (0.1 \times C_{NEIGHBOR}) \right] \times CF_2$$

where,

$RAE_{MEDIUM}$  = Medium Specific Estimated Receptor Acute Exposure  
(mg/dose)

$IR_{RECEPTOR}$  = Receptor Specific Medium Ingestion Rate, SIR(kg/day); WIR(L/day)

$C_{SUBJECT}$  = Contaminant Exceedance Concentration based on land-use and soil type remediation guideline values (mg/kg soil, mg/L water)  
(= measured – background concentration – guideline value)

$C_{NEIGHBOR}$  = Contaminant Exceedance Concentration based on land-use and soil type remediation guideline values (mg/kg soil, mg/L water) for neighboring property  
= (measured – background concentration – guideline value)

$CF_2$  = Dose Conversion Factor (= 154 day/dose)

Step 3: Determine the Acute Dosage Ratio,  $ADR_{ECOL}$ . This ratio represents the proportion of the acute dosage to which the receptor is actually exposed.

**Equation 5–22: Acute Dosage Ratio,  $ADR_{ECOL}$** 

$$ADR_{ECOL} = \frac{RAE_{SOIL} + RAE_{WATER}}{RAD_{ECOL}}$$

where,

$ADR_{ECOL}$  = Acute Dosage Ratio (unitless)

$RAE_{SOIL}$  = Chemical Specific Receptor Acute Exposure - Soil(mg/dose)

$RAE_{WATER}$  = Chemical Specific Receptor Acute Exposure - Water (mg/dose)

$$RAD_{ECOL} = \text{Estimated Receptor Acute Dosage (mg/dose)}$$

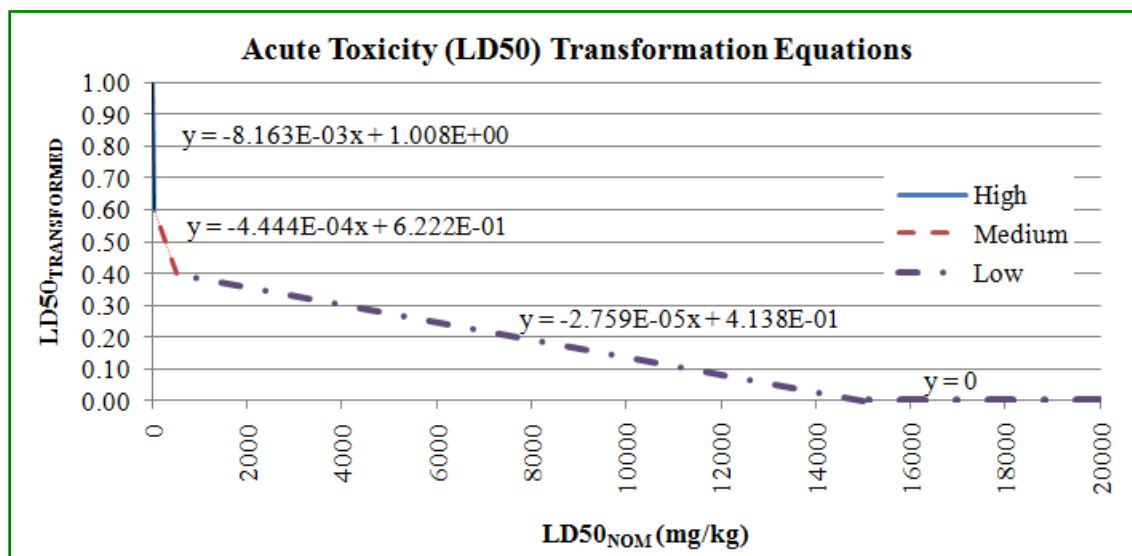
**Step 4:** Determine the Toxicity Weight. The Hodge and Sterner Toxicity Classification Scale is a scale developed in the early 1940's (Hodge and Sterner 1956) and continues to be used today in the field of toxicology and is referenced by the Canadian Centre for Occupational Health and Safety (CCOHS 2005). The numerical values for the levels identified in the scale were used to form the boundaries for the Toxicity Level of Concern values and subsequent linear transformation equations; toxicity ratings from relatively harmless to slightly toxic formed the “low” *Level of Concern* category, the moderately toxic formed the “medium” category and the highly to extremely toxic ratings formed the “high” category boundaries. These scales and transformation equations are shown in the following tables:

**Table 5-23: Toxicity Classification (Hodge and Sterner Scale)**

| TOXICITY RATING       | ROUTE OF ADMINISTRATION                    |
|-----------------------|--|
|                       | ORAL LD <sub>50</sub> (MG/KG, SINGLE DOSE) |
| Relatively Harmless   | 15,000 < LD <sub>50</sub>                  |
| Practically Non-Toxic | 5000 < LD <sub>50</sub> ≤ 15,000           |
| Slightly Toxic        | 500 < LD <sub>50</sub> ≤ 5000              |
| Moderately Toxic      | 50 < LD <sub>50</sub> ≤ 500                |
| Highly Toxic          | 1 < LD <sub>50</sub> ≤ 50                  |
| Extremely Toxic       | LD <sub>50</sub> ≤ 1                       |

**Table 5-24: Acute Toxicity (LD<sub>50</sub>) Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE   | LD <sub>50</sub> -NOMINAL (MG/KG <sub>bw</sub> ) | TOXICITY WEIGHT, TW <sub>LD50</sub> (UNITLESS)                 |
|------------------|---------------|--|--|
| Low              | 0.0 ≤ x ≤ 0.4 | 15,000 < LD <sub>50</sub> -NOM                   | TW <sub>LD50</sub> = 0.0                                       |
|                  |               | 500 < LD <sub>50</sub> -NOM ≤ 15,000             | TW <sub>LD50</sub> = (-2.759E-05)LD <sub>50</sub> -NOM + 0.414 |
| Medium           | 0.4 ≤ x ≤ 0.6 | 50 < LD <sub>50</sub> -NOM ≤ 500                 | TW <sub>LD50</sub> = (-4.444E-04)LD <sub>50</sub> -NOM + 0.622 |
| High             | 0.6 ≤ x ≤ 1.0 | 1 < LD <sub>50</sub> -NOM ≤ 50                   | TW <sub>LD50</sub> = (-8.163E-03)LD <sub>50</sub> -NOM + 1.008 |
|                  |               | LD <sub>50</sub> -NOM ≤ 1                        | TW <sub>LD50</sub> = 1.0                                       |

**Figure 5—8: Acute Toxicity (LD<sub>50</sub>) Transformation Equations**

Step 5: This is the final step in determining the Estimated Ecological Toxicity (ET<sub>ECOL</sub>). ET<sub>ECOL</sub> is the ratio of the product of Acute Dosage Ratio (ADR) and the transformed chemical specific acute toxicity weight (TW<sub>LD50</sub>) to the total maximum toxicity weight available for the contaminants identified. If the ADR >1.0 (i.e. the exposure dose

exceeds the acute dose), the  $ADR = 1.0$ . Otherwise, the  $ADR = ADR$ . The ratio formula provides an  $ET_{ECOL}$  that is indicative of a *Level of Concern* value between 0.0 and 1.0.

**Equation 5–23: Estimated Ecological Toxicity ( $ET_{ECOL}$ )**

$$ET_{ECOL} = \frac{\sum_{j=1}^n [ADR_j \times TW_{LD50}]}{TTW_{LD50}}$$

where,

$ET_{ECOL}$  = Level of Concern for SITE under assessment (unitless)

j = Counter for number of contaminants

ADR = Acute Dosage Ratio (unitless) - see Equation 5–22

$TW_{LD50}$  = Transformed Acute Toxicity (unitless)

$TTW_{LD50}$  = Total toxicity weight for contaminants identified onsite (soil and/or water)

#### 5.4.3.2.3 Estimated Ecological Bioaccumulation ( $EB_{ECOL}$ )

Wherein the Estimated Ecological Toxicity,  $ET_{ECOL}$ , requires the identification of a specific receptor for its evaluation, the  $EB_{ECOL}$  does not. The  $EB_{ECOL}$  provides a means of identifying the *tendency* of a substance to accumulate in terrestrial and aquatic organisms through direct exposure to the surrounding medium or by consumption of food containing the offending substance(s) through the use of chemical specific properties alone. Bioaccumulation guidance documents in Canada state specific criteria to identify bioaccumulative substances. The regulations identify these substances based on receptor specific bioaccumulation factors (account for substance intake from food and surrounding medium), bioconcentration factors (account for substance intake from surrounding medium only) and, in the absence receptor specific data, the octanol-water partition coefficient ( $\log K_{ow}$ ). (Environment Canada 2003; 2006a) These criteria are only applicable to water-respiring organisms in aquatic food chains and are inadequate for air-respiring organisms in terrestrial food chains. In 2008, The Society of Environmental Toxicology and Chemistry (SETAC) Workshop developed a five-stage science-based



framework for evaluating the bioaccumulation potential of organic substances (Gobas et al. 2009). The first three stages involve site specific screening (field studies on receptors) while the last two stages use the same criteria as recommended by Canada including an additional parameter, the octanol-air partition coefficient (log K<sub>oa</sub>) to facilitate bioaccumulation assessments of terrestrial organisms. As the data available included soil and groundwater sampling results and not specific bioaccumulation/bioconcentration field studies, bioaccumulation screening will follow the guidelines set forth by Environment Canada and incorporate the findings of SETAC. Thus, EB<sub>ECOL</sub> will be derived through the combination of three chemical specific parameters:

1. Log Octanol-Water Partition Coefficient, Log K<sub>ow</sub>
2. Log Octanol-Air Partition Coefficient, Log K<sub>oa</sub>
3. Fish Bioconcentration Factor.

The first two parameters are known as partition coefficients. A partition coefficient is a physical chemical property of a substance that describes how it distributes/partitions itself between two phases (soil-liquid, solid-solid, gas-liquid, etc) and is expressed as a concentration ratio. Partition coefficients are useful in describing the potential environmental fate of organic compounds. (LaGrega et al. 2001)

The octanol-water partition coefficient, K<sub>ow</sub>, is a dimensionless constant that indicates the ratio of a chemical's concentration in the octanol phase to its concentration in the water phase in an octanol-water mixture (Government of Canada 2000). This parameter provides an indication of how much of a chemical will be taken up by *aquatic* organisms. Octanol (an eight carbon chain fatty alcohol) is used because it behaves similarly to organic matter and lipids in nature (Schnoor 1996). Measured log K<sub>ow</sub> values for organic compounds typically range from -3 to 7, but can be higher. The higher the log K<sub>ow</sub>, the greater the hydrophobicity (i.e. "water fearing") and the greater the tendency to of the chemical to partition itself to an organic phase (fatty tissue). The lower the log K<sub>ow</sub>, the greater the hydrophilicity, or "water-loving" nature of the compound. These compounds preferentially stay in the aqueous phase and have a greater tendency to move through the environment. (LaGrega et al. 2001) It should

be noted that the  $K_{OW}$  provides only an indication of the *potential* for bioaccumulation in *water respiring aquatic organisms*, it does not account for the rates of biotransformation and elimination as it is a chemical property. Thus, the sole use of hydrophobicity as an indicator for bioaccumulation could produce false-positive results. (Gobas et al. 2009; Weisbrod et al. 2007)  $K_{OW}$  values are readily available through various database systems and reference books, or can be calculated by the use of various methods/models.

The octanol-air partition coefficient,  $K_{OA}$  is a dimensionless constant that indicates the ratio of a chemical's concentration in an octonal phase to its concentration in air. It is related to the volatility of the compound and is considered a key descriptor for describing the partitioning of organic pollutants, especially persistent organic pollutants (POPs), between the air and environmental organic matter, such as soil vegetation and aerosol particles (Harner and Bidleman 1998; Kelly et al. 2008; Meylan and Howard 2005; Sepassi and Yalkowsky 2007; Sijm 2001; Su et al. 2002; Zhang et al. 1999). As inhalation has been described as the most important route of inadvertent entry of chemicals into biota the integration of  $K_{OA}$  into bioaccumulation screening for *air-respiring organisms* is recommended. (Gobas et al. 2009; Sijm 2001) Log  $K_{OA}$  values range from the negative values to +14. As seen with the  $K_{OW}$  values, the higher the  $K_{OA}$  the greater the tendency for chemical partitioning to lipids and hence, the greater the tendency for bioaccumulation, and vice versa. Data is easily obtainable through field studies, database systems, reference books and through calculations.

The third parameter used in screening bioaccumulation potential is the Bioconcentration Factor, BCF. The BCF is a dimensionless constant that indicates the ratio of a chemical's concentration in an organism to its concentration in the ambient environment. The most common approach is to use BCFs derived from conventional laboratory studies where a steady state has been attained between the chemical, the receptor and the environment. A steady state condition is required to ensure the maximum concentration is reached. The BCF is typically associated with *aquatic organisms*, typically fish, and several methods for estimating these values are available. The most common involves the relationship between BCF and the partition coefficient  $K_{OW}$ . In the absence of site-specific BCF

analysis values, the values from literature may be used for screening purposes as it only accounts for chemical bioaccumulation from water but not from the diet. (Gobas et al. 2009; Suter et al. 2007; Walker et al. 2006)

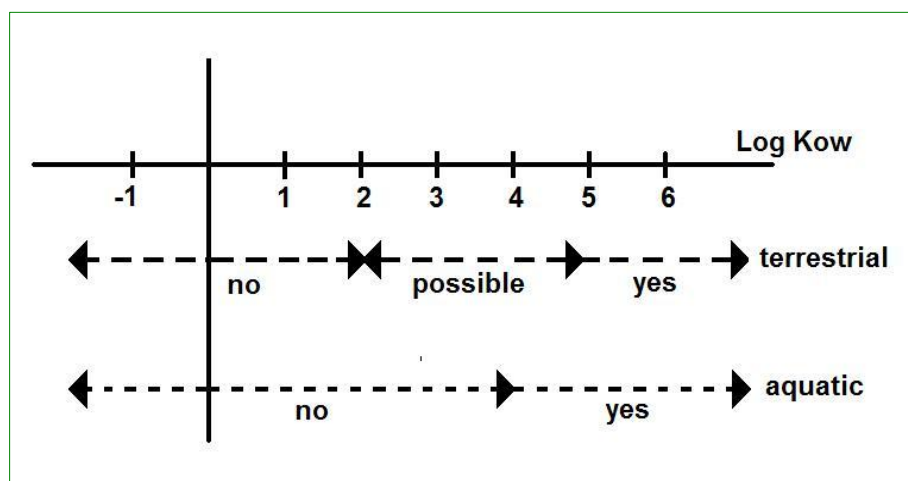
The USEPA has developed an Estimation Programs Interface (EPI) Suite program as a screening-level tool which provides a variety of data that can be readily accessed via chemical name or chemical specific Chemical Abstract Service Registry Number (CASRN) (USEPA 2000-2009). This program was used as the primary source for the compilation of the bioaccumulation reference data; Log  $K_{OA}$ , Log  $K_{OW}$ , and BCF.

In order to establish a method of classifying the bioaccumulation tendency, several sources were reviewed for bioaccumulation criteria. The results are summarized in Table 5-25.

**Table 5-25: Bioaccumulation Assessment Endpoints and Criteria**

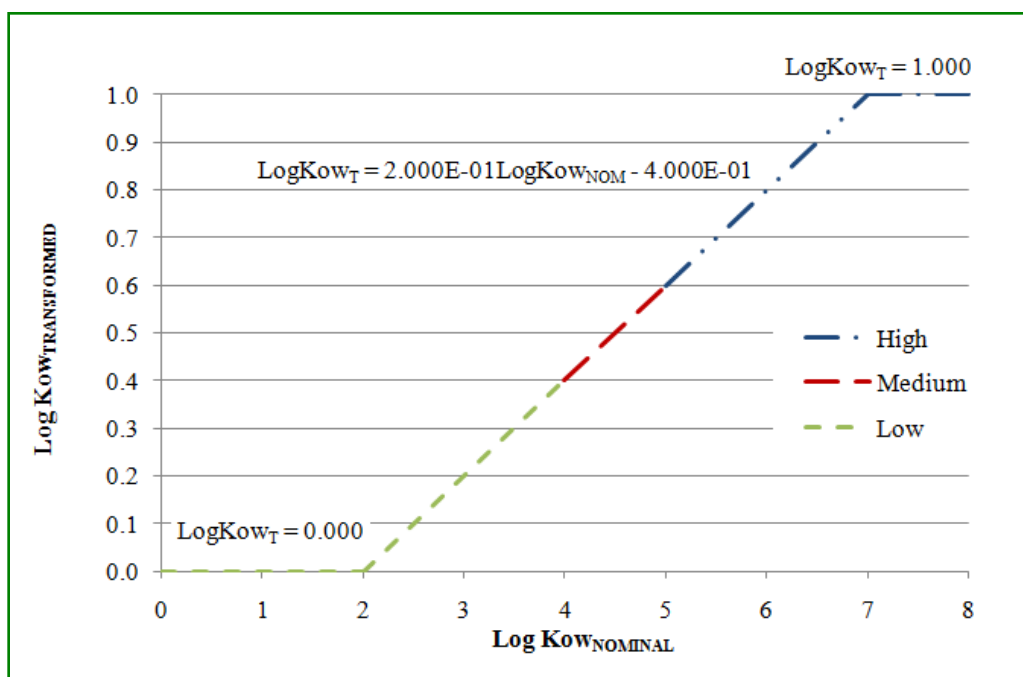
| ENDPOINT CRITERIA   | BIOACCUMULATION TENDENCY | SOURCE  |
|---|--------------------------|---|
| $BCF \geq 5000$   | yes                      | (Environment Canada 2003; 2006a)  |
| $\text{Log } K_{ow} \geq 5$   | yes                      | (Environment Canada 2003; 2006a)  |
| $\text{Log } K_{ow} \geq 6$   | yes                      | (Arnot and Gobas 2006)  |
| $\text{Log } K_{ow} < 4$  | no                       | (Arnot and Gobas 2006)  |
| $\text{Log } K_{ow} \leq 2$   | no                       | (Gobas et al. 2009; Undeman et al. 2009)  |
| $BCF \leq 5000 \text{ \& } \text{Log } K_{ow} \leq 5$                     | no                       | (Gobas et al. 2009)   |
| $BCF < 5000 \text{ \& } \text{Log } K_{ow} > 6$                           | possible                 | (Gobas et al. 2009)   |
| $\text{Log } K_{oa} < 4$  | no                       | (Arnot and Gobas 2006)  |
| $\text{Log } K_{oa} > 3.5$  | possible                 | (Czub and McLachlan 2004)   |
| $BCF < 5000 \text{ \& } \text{Log } K_{oa} < 4$                           | no                       | (Arnot and Gobas 2006)  |
| $\text{Log } K_{oa} > 5 \text{ to } 6 \text{ \& } \text{Log } K_{ow} < 5$ | possible                 | (Armitage and Gobas 2007; Gobas and Arnot 2003; Gobas et al. 2009; Kelly et al. 2008) |
| $\text{Log } K_{oa} > 5 \text{ \& } \text{Log } K_{ow} \leq 2$            | no                       | (Armitage and Gobas 2007; Gobas and Arnot 2003; Gobas et al. 2009; Kelly et al. 2008) |
| $\text{Log } K_{oa} > 11 \text{ \& } \text{Log } K_{ow} > 6$              | yes                      | (Undeman et al. 2009)   |

In order to determine the boundaries of the Levels of Concern for the  $\text{Log } K_{ow}$  the results tabulated above were examined. Using the endpoint criteria identified and setting the  $\text{Log } K_{ow}$  as the foundation for data comparison, the bioaccumulation tendency was identified in both the terrestrial and aquatic environments and is depicted below.



**Figure 5—9: Bioaccumulation Tendency Based on Log K<sub>ow</sub>**

When the Log K<sub>ow</sub> is greater than 5 the bioaccumulation tendency of a chemical exists in both the terrestrial and aquatic environments and when it is less than 2, it exists in neither. These boundaries hold true regardless of the BCF or Log K<sub>oa</sub>. However, when the Log K<sub>ow</sub> values are between 2 and 5, the bioaccumulation tendency differs between the terrestrial and aquatic environments. The Log K<sub>ow</sub> *Levels of Concern* and subsequent linear transformation equations were defined based on the findings in Figure 5—9 and Figure 5—10, and are provided in Table 5-26.



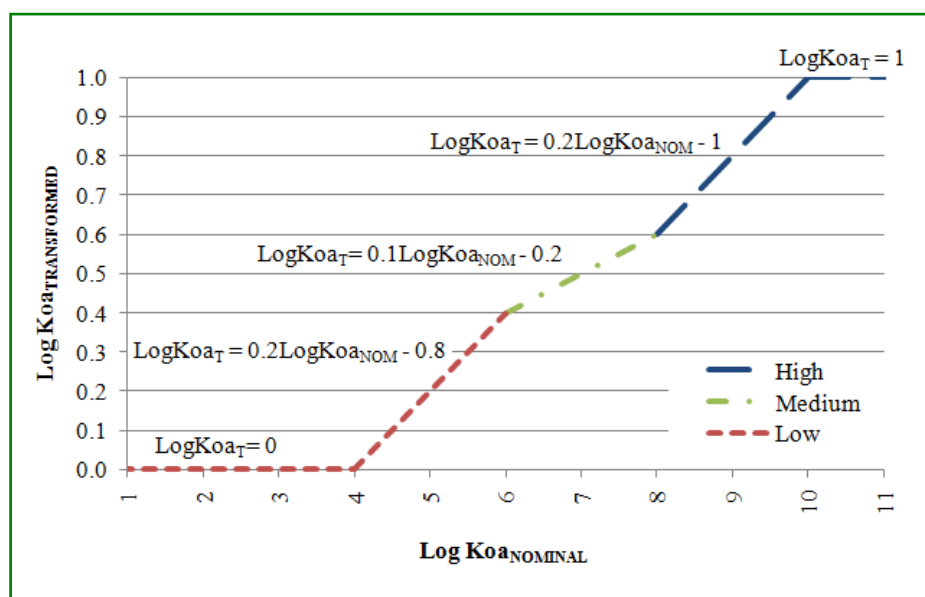
**Figure 5—10: Log Kow Transformation Equations**

**Table 5-26: Log Kow Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | LOG KOW <sub>NOMINAL</sub>               | LOG KOW <sub>TRANSFORMED</sub> (LKOW <sub>T</sub> )                   |
|------------------|-----------------------|--|---|
| Low              | $0.0 \leq x \leq 0.4$ | $\text{LKOW}_{\text{NOM}} < 2$           | $\text{LKOW}_T = 0.0$   |
|                  |                       | $2 \leq \text{LKOW}_{\text{NOM}} \leq 4$ | $\text{LKOW}_T = (2.000\text{E-}01) \text{LKOW}_{\text{NOM}} - 0.400$ |
| Medium           | $0.4 < x \leq 0.6$    | $4 \leq \text{LKOW}_{\text{NOM}} \leq 5$ | $\text{LKOW}_T = (2.000\text{E-}01) \text{LKOW}_{\text{NOM}} - 0.400$ |
| High             | $0.6 < x \leq 1.0$    | $5 \leq \text{LKOW}_{\text{NOM}} \leq 7$ | $\text{LKOW}_T = (2.000\text{E-}01) \text{LKOW}_{\text{NOM}} - 0.400$ |
|                  |                       | $7 \leq \text{LKOW}_{\text{NOM}}$        | $\text{LKOW}_T = 1.000$   |

In the case of the Log K<sub>OA</sub> parameter, only upper and lower boundaries were available through research. The Log K<sub>OA</sub> values identified for the contaminant tested for in the Phase II ESA's, ranged from less than zero to slightly greater than 13. Thus, using the Log K<sub>OA</sub> values identified in Figure 5—9 and the range available, the intermediate value

ranges for the Levels of Concern were established. The transformation equations were developed the linear representation of the *Level of Concern* value range and the nominal Log K<sub>OA</sub> values (Figure 5—11). The *Level of Concern* and transformation equations are presented in Table 5-27.



**Figure 5—11: Log K<sub>oa</sub> Transformation Equations**

**Table 5-27: Log Koa Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | LOG KOA <sub>NOMINAL</sub>   | LOG KOA <sub>TRANSFORMED</sub> (LKOAT)                     |
|------------------|-----------------------|------------------------------|--|
| Low              | $0.0 \leq x \leq 0.4$ | $\text{LKOANOM} < 4$         | $\text{LKOAT} = 0.0$                                       |
|                  |                       | $4 \leq \text{LKOANOM} < 6$  | $\text{LKOAT} = (2.000\text{E-}01) \text{LKOANOM} - 0.800$ |
| Medium           | $0.4 < x \leq 0.6$    | $6 \leq \text{LKOANOM} < 8$  | $\text{LKOAT} = (1.000\text{E-}01) \text{LKOANOM} - 0.200$ |
| High             | $0.6 < x \leq 1.0$    | $8 \leq \text{LKOANOM} < 10$ | $\text{LKOAT} = (2.000\text{E-}01) \text{LKOANOM} - 1.000$ |
|                  |                       | $10 \leq \text{LKOANOM}$     | $\text{LKOAT} = 1.000$                                     |

According to Table 5-25, bioconcentration is known to occur with bioconcentration factors  $\geq 5000$  but can also occur for  $BCF < 5000$ . The BCF data available/identified for the contaminants tested in the Phase II ESA's range from approximately 3000 to 12000. As the only reference value provided for the BCF parameter is 5000, it is used as the base of the medium *Level of Concern* category. Since bioconcentration can occur at  $BCF < 5000$ , the threshold value is selected to be 4000. This 1000 point spread is used as the base range for the remaining categories. In order to determine the transformation equations, the *Level of Concern* ranges were plotted versus the nominal BCF ranges (Figure 5—12). The BCF and *Level of Concern* ranges selected are provided in Table 5-28 with the linear transformation equations.

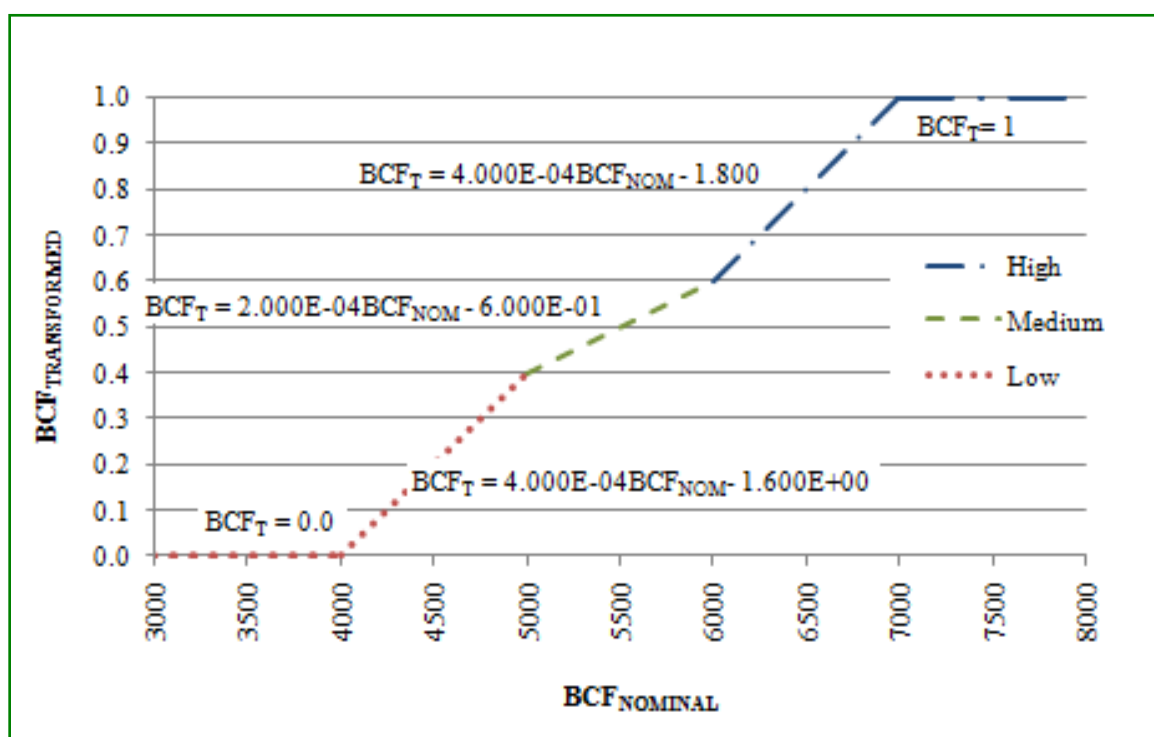


Figure 5—12: BCF Transformation Equations



**Table 5-28: BCF Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE   | BCF <sub>NOMINAL</sub>           | BCF <sub>TRANSFORMED</sub> (BCF <sub>T</sub> )           |
|------------------|---------------|----------------------------------|--|
| Low              | 0.0 ≤ x ≤ 0.4 | BCF <sub>NOM</sub> < 4000        | BCF <sub>T</sub> = 0.000                                 |
|                  |               | 4000 ≤ BCF <sub>NOM</sub> < 5000 | BCF <sub>T</sub> = (4.000E-04)BCF <sub>NOM</sub> - 1.600 |
| Medium           | 0.4 < x ≤ 0.6 | 5000 ≤ BCF <sub>NOM</sub> < 6000 | BCF <sub>T</sub> = (2.000E-04)BCF <sub>NOM</sub> - 0.600 |
| High             | 0.6 < x ≤ 1.0 | 6000 ≤ BCF <sub>NOM</sub> < 7000 | BCF <sub>T</sub> = (4.000E-04)BCF <sub>NOM</sub> - 1.800 |
|                  |               | 70000 ≤ BCF <sub>NOM</sub>       | BCF <sub>T</sub> = 1.000                                 |

As the potential for bioaccumulation in both aquatic and terrestrial biota are affected by the Log K<sub>ow</sub> (see combinatorial restrictions in Table 5-25), two separate sets of calculations are developed. The Aquatic Biota Bioaccumulation (ABB<sub>ECOL</sub>) is derived from the summation of the combination of the transformed Log K<sub>ow</sub> and BCF for each contaminant found in the groundwater prorated with the specific chemical's contribution to the amount of contaminants detected in groundwater on-site. As the transformed variables and the chemical specific fraction each have a potential maximum of 1.0, the total numerical possible is 2.0. To facilitate the transformation of the ABB<sub>ECOL</sub> into one of the *Level of Concern* ranges the final summation value is normalized by dividing through by 2.0 (Equation 5–24).

**Equation 5–24: Aquatic Biota Bioaccumulation (ABB<sub>ECOL</sub>)**

$$ABB_{ECOL} = \frac{1}{2} \sum_{j=1}^n [LKow_T + BCF_T]_j \times CSF_j$$

where,

ABB<sub>ECOL</sub> = Level of Concern for Aquatic Bioaccumulation (unitless)

j = Counter for number of contaminants

LKow<sub>T</sub> = Transformed Log Kow value (unitless)

$BCF_T$  = Transformed Fish BioConcentration Factor (unitless)

$CSF$  = Chemical Specific Fraction (unitless) – see Equation 5–18

The Terrestrial Biota Bioaccumulation,  $TBB_{ECOL}$  is derived from the summation of a combination of the transformed LogKOW and LogKOA for each contaminant found in the soil and groundwater prorated to its contribution to the amount of contaminants detected in the soil on-site. Both soil and groundwater contributions are required as terrestrial organisms are doubly exposed if both media are compromised. As with the  $ABB_{ECOL}$ , the total numerical result from the summation of the variables is 2.0 for each media so to facilitate transformation of the result to one of the *Level of Concern* ranges, the summation result is normalized by dividing through by the maximum attainable value of 4.0 (Equation 5–25).

**Equation 5–25: Terrestrial Biota Bioaccumulation ( $TBB_{ECOL}$ )**

$$TBB_{ECOL} = \frac{1}{4} \sum_{i=1}^2 \sum_{j=1}^n [LKow_T + LKoa_T]_j \times CSF_j$$

where,

$TBB_{ECOL}$  = Level of Concern for Terrestrial Bioaccumulation (unitless)

$j$  = Counter for number of contaminants

$i$  = Media Count ( 1 = soil, 2 = groundwater)

$LKow_T$  = Transformed Log Kow value (unitless)

$LKoa_T$  = Transformed Log Koa value (unitless)

$CSF$  = Chemical Specific Fraction (unitless) – see Equation 5–18

The final/overall Estimated Biota Bioaccumulation,  $EBB_{ECOL}$ , is derived from the equal contributions of the aquatic and terrestrial biota accumulations. As each of these have the capacity to contribute a maximum of 1.0, and a *Level of Concern* classification value is

required, the resulting summation is normalized by dividing through by the maximum possible score (2.0).

**Equation 5–26: Estimated Biota Bioaccumulation ( $EBB_{ECOL}$ )**

$$EBB_{ECOL} = \frac{ABB_{ECOL} + TBB_{ECOL}}{2}$$

where,

$ABB_{ECOL}$  = Estimated Aquatic Bioaccumulation (unitless)

$TBB_{ECOL}$  = Estimated Terrestrial Bioaccumulation (unitless)

**5.4.3.3 Estimated Mobility & Groundwater Contamination Factor ( $MGCF_{ECOL}$ )**

Contaminant transport through the soil depends on the physical properties of the chemical, the properties of the soil, and environmental conditions. Transport occurs through volatilization and leaching. The fate of a chemical is determined by the degree to which it moves and its stability in the areas once it has moved. It is the final fate of the chemical that contributes to the risk characterization of the site. (Charbeneau et al. 2003; Drillia et al. 2005; McCall et al. 1981) Movement of chemicals into the food chain and their toxic effects has already been addressed with the previous parameters. The final criterion to be examined is the potential for movement of contaminants into the groundwater system. As the remediation of contaminated groundwater can be time and labor intensive, and ultimately costly, it is important to identify the potential that may exist with a contaminated site.

Sorption coefficients can be used to assess the mobility potential of chemicals through the soil. (McCall et al. 1981) They can provide a means of ranking and comparing chemicals. When a chemical enters the soil, it partitions between the soil particles, particularly organic matter, (adsorption) and the soil water (dissolution). The soil organic carbon content normalized adsorption coefficient,  $K_{OC}$ , is a chemical-specific parameter

that is commonly used as an indicator of the distribution of organic compounds between soil and water. It is universally used as a measure of the relative potential mobility of organic compounds in soil, particularly pesticides. (Gerstl 1990; 2000; McCall et al. 1981; Wauchope et al. 2002; Zhao et al. 2006) While it is generally *independent* of soil properties, variations in values can occur in their derivation and application resulting in overestimation or underestimation of the sorption process (Cornejo et al. 2004; Gerstl 1990). Despite certain inherent problems with this parameter, it does provide an excellent tool for estimating the risk of contaminant leaching into groundwater, providing a means of relative mobility comparisons between substances and thereby facilitating decision-making when actual site specific data is lacking (FAO United Nations 2000; Gerstl 1990; 2000; McCall et al. 1981; Wauchope et al. 2002; Zhao et al. 2006).

As mentioned above, the  $K_{OC}$  is the ratio of the concentration of chemical in the organic carbon component of soil to the concentration of the chemical in water (LaGrega et al. 2001). The interpretation of the ratio is similar to the  $K_{OW}$  and  $K_{OA}$  partition coefficients; the greater the  $K_{OC}$  the greater the tendency to bind with the organic carbon component. In order to assess compounds' leaching/mobility potential the concentration of the chemical in the water should be greater than in the soil. Thus, the smaller the  $K_{OC}$  the greater the tendency to move from the soil and leach into groundwater. The logarithm of the  $K_{OC}$  is generally used to simplify mobility classification.

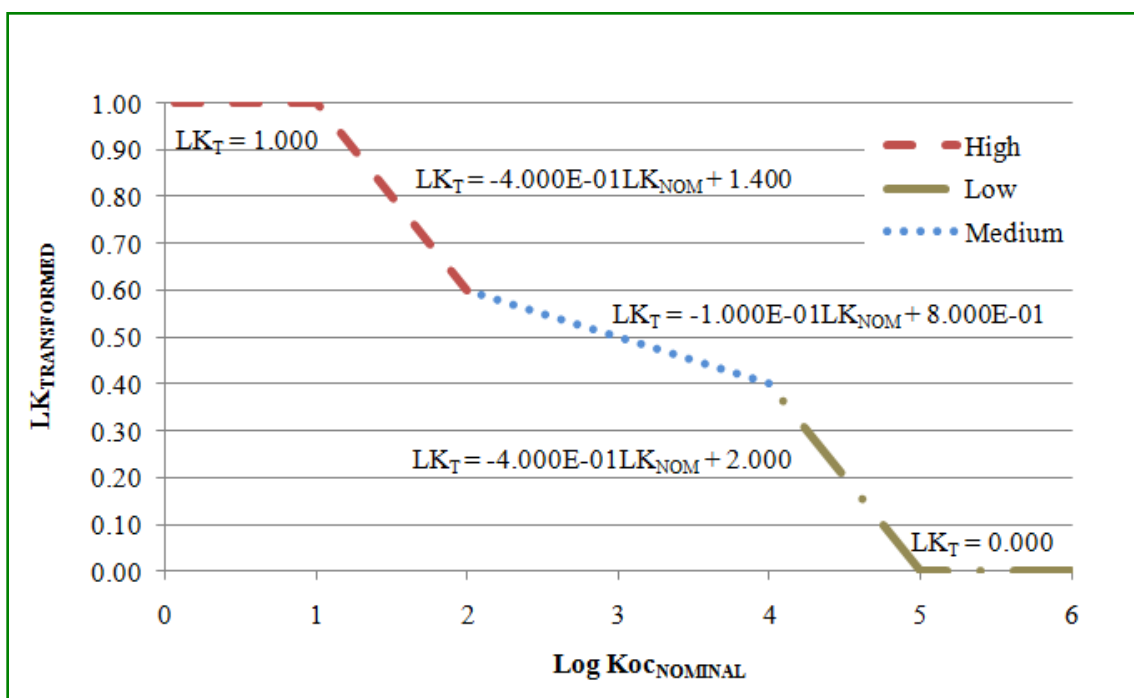
In order to determine the Estimated Mobility attribute,  $EM_{ECOL}$ , the boundaries of the Levels of Concern for the  $\log K_{OC}$  values and their subsequent transformation equations, were developed based on a combination of the low-medium-high categories previously identified and the classification scheme provided by the Food and Agriculture Organization of the United Nations for contaminant mobility in soil (FAO United Nations 2000). These scales and transformation equations are shown in the following tables and figure:

**Table 5-29: FAO United Nations Mobility Classification Scale**

| CLASSIFICATION    | LOG K <sub>OC</sub>                   |
|-------------------|---------------------------------------|
| Immobile          | $5 < \text{LOG K}_{\text{OC}}$        |
| Hardly Mobile     | $4 < \text{LOG K}_{\text{OC}} \leq 5$ |
| Slightly Mobile   | $3 < \text{LOG K}_{\text{OC}} \leq 4$ |
| Moderately Mobile | $2 < \text{LOG K}_{\text{OC}} \leq 3$ |
| Mobile            | $1 < \text{LOG K}_{\text{OC}} \leq 2$ |
| Highly Mobile     | $\text{LOG K}_{\text{OC}} \leq 1$     |

**Table 5-30: Mobility Potential Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | LOG K <sub>OCNOMINAL</sub>               | LOG K <sub>OC</sub> TRANSFORMED, (LK <sub>T</sub> )                     |
|------------------|-----------------------|--|---|
| Low              | $0.0 \leq x \leq 0.4$ | $5 < \text{LOG K}_{\text{OCNOM}}$        | $\text{LK}_T = 0.0$   |
|                  |                       | $4 < \text{LOG K}_{\text{OCNOM}} \leq 5$ | $\text{LK}_T = (-4.000\text{E-}1) \text{LOG K}_{\text{OCNOM}} + 2.000$  |
| Medium           | $0.4 < x \leq 0.6$    | $2 < \text{LOG K}_{\text{OCNOM}} \leq 4$ | $\text{LK}_T = (-1.000\text{E-}01) \text{LOG K}_{\text{OCNOM}} + 0.800$ |
| High             | $0.6 < x \leq 1.0$    | $1 < \text{LOG K}_{\text{OCNOM}} \leq 2$ | $\text{LK}_T = (-4.000\text{E-}01) \text{LOG K}_{\text{OCNOM}} + 1.400$ |
|                  |                       | $\text{LOG K}_{\text{OCNOM}} \leq 1$     | $\text{LK}_T = 1.000$   |



**Figure 5—13: Log Koc Transformation Equations**

The KOCWIN application of the USEPA's EPI Suite program was used as the source for the Log K<sub>OC</sub> values. The application provides two estimates for K<sub>OC</sub>: one utilizing an estimate from Log K<sub>OW</sub> and another from a First Order Molecular Connectivity Index(MCI). The method of estimation can provide different K<sub>OC</sub> values, as previously mentioned. For example, in the case of benzene the K<sub>OC</sub> estimate from the Log K<sub>OW</sub> provided a value of 70.51 L/kg (Log K<sub>OC</sub> = 1.8482) which is nearly half the the K<sub>OC</sub> estimate from the MCI, 145.8L/kg (Log K<sub>OC</sub> = 2.1637). For vinyl chloride, the difference is less marked (25.44 L/kg via Log K<sub>OW</sub> method; 21.73 L/kg via MCI method). (USEPA 2000-2009) For screening purposes, the K<sub>OC</sub> values selected were from the Log K<sub>OW</sub> estimation method. This decision was based on the research performed by Gerstl wherein the use of MCI methodology was found to be inadequate for predictive purposes compared to the Log K<sub>OW</sub> method which indicated a good correlation between the Log K<sub>OC</sub> and Log K<sub>OW</sub> values. (Gerstl 1990)

The Estimated Chemical Mobility ( $EM_{ECOL}$ ) is the transformed Log Koc prorated to the chemicals' contribution to the amount of contaminants detected *in the soil* on-site (i.e. chemical specific fraction).

**Equation 5–27: Estimated Chemical Mobility ( $EM_{ECOL}$ )**

$$EM_{ECOL} = \sum_{j=1}^n (LK_T \times CSF)_j$$

where,

$EM_{ECOL}$  = Specific Estimated Mobility Potential (unitless)

j = Counter for number of contaminants

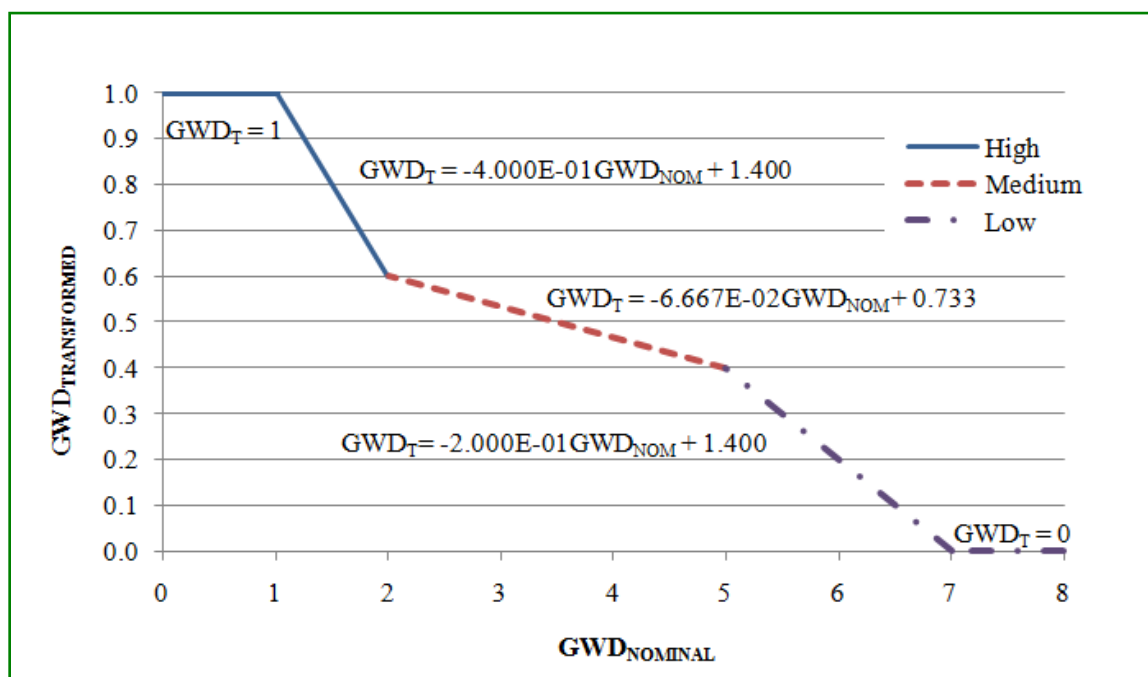
$LK_T$  = Transformed Log Koc

$CSF$  = Soil Chemical Specific Fraction (unitless) – see Equation 5–18

While the  $EM_{ECOL}$  provides an indication of the potential for contaminant transport to groundwater it does not completely identify the risk associated with contaminants on the site. Transport to groundwater also depends on the distance to be travelled, the amount of contaminant(s) spilled, elapsed time from source release, annual rainfall and the degradation rate of the substance. Of these possible inputs, the only other information that is readily available through the Phase II Environmental Site Assessment reports is the depth to groundwater. Thus, the second attribute of the  $MGC_{ECOL}$  parameter is the depth to groundwater,  $GWD_{ECOL}$ . The closer the groundwater is to the surface of the site, the shorter the distance chemical transport needs to traverse and hence the greater the risk to groundwater protection. The Food and Agriculture Organization of the United Nations provides a table to facilitate the prediction of contaminant transport towards the groundwater and identifies three depth categories: less than 2 meters, less than 5 meters and greater than 5 meters. (FAO United Nations 2000) Using these categories as a base and examining the depth to groundwater values for the available test sites, the Levels of Concern for the depth to groundwater and their subsequent transformation equations to  $GWD_{ECOL}$  were developed.

**Table 5-31: Depth to Groundwater Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | GROUNDWATER DEPTH<br>$GWD_{NOMINAL}$ (M) | GROUNDWATER DEPTH,<br>( $GWD_{TRANSFORMED}$ ) |
|------------------|-----------------------|--|---|
| Low              | $0.0 \leq x \leq 0.4$ | $7 < GWD_{NOM}$                          | $GWD_T = 0.0$                                 |
|                  |                       | $5 < GWD_{NOM} \leq 7$                   | $GWD_T = (-2.000E-01) GWD_{NOM} + 1.400$      |
| Medium           | $0.4 < x \leq 0.6$    | $2 < GWD_{NOM} \leq 5$                   | $GWD_T = (-6.667E-02) GWD_{NOM} + 0.7333$     |
| High             | $0.6 < x \leq 1.0$    | $1 < GWD_{NOM} \leq 2$                   | $GWD_T = (-4.000E-01) GWD_{NOM} + 1.400$      |
|                  |                       | $GWD_{NOM} \leq 1$                       | $GWD_T = 1.0$                                 |

**Figure 5—14: Groundwater Depth Transformation Equations**

The final Estimated Mobility and Groundwater Contamination Factor ( $MGCF_{ECOL}$ ) is derived through the combination of the transformed values of the two contributing attributes,  $GWD_{ECOL}$  and  $EM_{ECOL}$ . As each of the attributes can attain a maximum value of 1.0, the  $MGCF_{ECOL}$  is normalized with the maximum possible result, 2.0.



**Equation 5–28: Estimated Mobility & Groundwater Contamination ( $MGCF_{ECOL}$ )**

$$MGCF_{ECOL} = \frac{1}{2}(EM_{ECOL} + GWD_{ECOL})$$

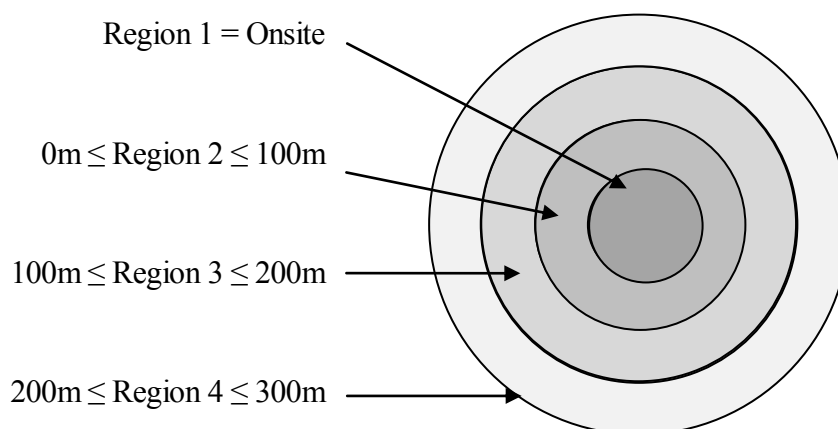
where,

$EM_{ECOL}$  = Estimated Chemical Mobility Attribute (unitless)

$GWD_{ECOL}$  = Groundwater Depth Attribute (unitless)

**5.4.3.4 Surface Water Proximity Parameter ( $SWP_{ECOL}$ )**

This parameter deals with the presence of surface water bodies on and surrounding the suspected contaminated site. Alberta Environment Tier 1 Soil and Groundwater Remediation Guidelines stipulate that water uses within a 300m radius should be identified. More specifically, if the groundwater gradient has been determined, then water bodies 100m up-gradient and 300m down-gradient should be identified. (AENV 2008b) In order to satisfy the Tier 1 recommendations, all surface water bodies present within a uniform 300m radius of the site are to be included in the assessment of the  $SWP_{ECOL}$  parameter. For the categorization of Levels of Concern, the 300m radius is sub-divided into 4 regions:



**Figure 5—15: Surface Water Proximity Regions**

Level 1 screening provided information for the first two regions. The information collected regarding water bodies is summarized in the following table:

**Table 5-32: Water Body Identification – Stage 2 Screening**

| ONSITE  | OFFSITE (WITHIN 100M)                               |
|---|---|
| Identification of <u>largest</u> water body <u>only</u> | Total number of water bodies                        |
| Presence and type of water wells                        | Total number of water bodies in each category       |
| Total number of water bodies & water wells              | Shortest distance to subject site for each category |

Level 1 screening provided a breakdown of water bodies based on type and each type/category had a risk level associated with it. For example, potable water bodies had the *highest* risk level whereas those other than potable, agricultural/recreational or ecological were rated as *low*. As all water bodies are considered to be a natural resource that needs to be protected regardless of their classification, the application of the separate water body rankings for this parameter was rejected in favor of a uniform risk level (i.e. 1.0). Thus, the data collected for the first two regions would be consolidated into total number of water bodies regardless of classification; the location within the region (i.e. distance from the source site) is not required. The data for Regions 3 and 4 would need to be collected either by the Consultant doing the Phase II ESA or by Municipality. For data collection, the total number of surface water bodies present in a region would be identified and recorded. If a water body extends through more than one region, such as a river or creek, it will be accounted for in each region it is present. While this may appear as providing multiple entries for the same water body, the risk associated with this water body increases as contaminant spread over greater distances is likely.

The SWP<sub>ECOL</sub> parameter is a combination of the number of water bodies within a region and their risk weight based on the Level of Concern associated with the region. The basic value ranges defined in Table 4-8 to represent high, medium and low perceived risk levels are used

as the foundation. The uppermost value is selected for the *low* risk level and the middle of the value range was selected for the *medium* risk level. For the *high* risk level, the uppermost and middle values of the range were selected for the *onsite* and *within 100m* regions, respectively (Table 5-33).

**Table 5-33: Surface Body Region Weight**

| LEVEL OF CONCERN | VALUE RANGE           | DEFAULT WEIGHT | BOUNDARIES                                       |
|------------------|-----------------------|----------------|--|
| Low              | $0.0 \leq x \leq 0.4$ | 0.40           | $200\text{m} < \text{Region 4} \leq 300\text{m}$ |
| Medium           | $0.4 < x \leq 0.6$    | 0.50           | $100\text{m} < \text{Region 3} \leq 200\text{m}$ |
| High             | $0.6 < x \leq 1.0$    | 0.8            | $0\text{m} < \text{Region 2} \leq 100\text{m}$   |
|                  |                       | 1.0            | Region 1 = Onsite                                |

Evaluation of the  $SWP_{ECOL}$  is a multistage process wherein water body quantity equivalencies are determined for each level (beginning at Region 4) and elevated to the region above prior to weighting and normalizing. The general equation is provided below followed by a stepwise description and illustration of the process.

**Equation 5–29: Surface Water Proximity ( $SWP_{ECOL}$ )**

$$SWP_{ECOL} = \frac{\sum_{i=1}^4 RW_i \times WBE_i}{25}$$

where,

- $i$  = Region
- RW = Region Weight
- WBE = Total number of water bodies equivalencies within specified region
- 25 = Normalizing Constant

Two water bodies in a given level are considered to be equivalent to 1 water body in the level immediately above.

Step 1: Beginning at Region 4. Determine the number of equivalencies by dividing the quantity by 2. The equivalencies must be integers and should be rounded downward in the case of 'odd' original quantity. The 'odd' water body remains in Region 4 and the equivalencies are elevated to Region 3.

Step 2: Determine the total number of Region 3 water bodies under by summing the identified with the equivalencies. Divide this quantity by 2 to obtain the Region 2 equivalencies. Any 'odd' water body quantities (generally 1) remain in Region 3 and the equivalencies are elevated to Region 2.

Step 3a: IF Region 1 does not have any water bodies identified, all water bodies from Region 2 remain at the Region 2 level. Proceed to Step 5.

Step3b: Repeat Step 2 for Region

Step 5: Multiply the number of water bodies in each region by their respective weights and tally to obtain a final total.

Step 6: Normalize the resulting value by dividing by 25(constant). This value was selected based on the number of water bodies onsite and within 100m identified in the Stage 1 Screening Database, identification of outliers as per Equation 4–17, and the aforementioned process. The outlier reference value for the onsite and offsite (Region 1 & 2) water bodies was 22.8 and 4, respectively. Region 2 has two (2) Level 1 equivalencies providing  $22.8 + 2 \approx 25$  Level 1 sites. Application of the Level 1 weight (1.0) to these sites results in the normalizing constant of 25.








|   |    |   |     |   |    |   |    |
|---|----|---|-----|---|----|---|----|
| <b>Region 1</b>   |    |   |     |   |    |   |    |
| Total Q2 =3   | A  | Z*  | Z** |   |    |   |    |
| Qnominal =1   | A  |   |     |   |    |   |    |
| <b>Region 2</b>   |    |   |     |   |    |   |    |
| Q2remain = 1  | Z* |   |     |   |    | Z**   |    |
| Q1equiv =1  |    |   |     |   |    |    |    |
| Total Q2 = 3  |    | Z*  |     | Z*  |    |   | Z* |
| Q2nominal = 0   |    |   |     |   |    |   |    |
| <b>Region 3</b>   |    |   |     |   |    |   |    |
| Q3remain =1   | Z  |   | Z*  |   | Z* |   | Z* |
| Q2equiv = 3   |    |   |     |   |    |   |    |
| Total Q3 = 7  | Z  | Z   | Z   | Z   | X* | X*  | X* |
| Q3nominal = 4   | Z  | Z   | Z   | Z   |    |   |    |
| <b>Region 4</b>   |    |   |     |   |    |   |    |
| Q4remain = 1  | X  |   |     |   |    |   |    |
| Q3equiv = 3   |    |  |     |  |    |  |    |
| Q4nominal = 7   | X  | X   | X   | X   | X  | X   | X  |
| * = equivalent waterbody  |    |   |     |   |    |   |    |
| $SWP_{ECOL} = \frac{3 * (1.0) + 1 * (0.8) + 1 * (0.5) + 1 * (0.4)}{25} = 0.188$ |    |   |     |   |    |   |    |

Figure 5—16: SWP<sub>ECOL</sub> Equation Illustrated

#### 5.4.3.5 Salinity Effect ( $SE_{ECOL}$ )

The final area of concern to be addressed for the ecological component of the Level 3 MODM is that of soil and water chemistry. In the previous subsections, the effect of contamination on terrestrial and aquatic organisms has been based on toxicological benchmarks of specific contaminants in their original/complete form. That is, the specific substance identified has not undergone any changes through dissolution, degradation, bio-uptake and metabolism. Soil and water are **the** source of nutrients for all living organisms and changes to their chemistry can have a detrimental effect of significant proportion. The  $SE_{ECOL}$  provides an assessment of the effect ionic changes can have when certain elements are released into the environment, namely sodium and chloride.

Approximately five million tonnes of chloride salts are released into the environment per year in the form of road salts, resulting in contamination of soil, increased chemical loading to surface water bodies either through direct runoff from impermeable surfaces within municipalities or through groundwater infiltration and transport to nearby surface water bodies and adversely impacting both terrestrial and aquatic habitats. The City of Calgary applies approximately 30,000 to 40,000 tonnes of road salts during the winter months (The City of Calgary 2009). High use areas such as major expressways, point contamination areas such as salt depots, salt/sand processing and storage facilities at highway maintenance yards, runoff from snow removal dumps and the transportation of saline material for industrial use are of major concern. Liability claims against Municipalities range from property damage to water well contamination from the salt release. (AENV 2001b; Amirsalari and Li 2007; Environment Canada 2006b)

All road salts are inorganic chloride salts such as sodium chloride ( $NaCl$ ), calcium chloride ( $CaCl_2$ ), magnesium chloride ( $MgCl_2$ ) and potassium chloride ( $KCl$ ), and some may even contain ferrocyanide additives which when dissolved release cyanide into the environment. These products may be dispersed as liquids (brines) or as solids (abrasive mixtures). The large quantities of these being released may constitute a hazard to the environment and are considered “toxic”. Environment Canada has developed a ‘Code of Practice’ which

municipalities can use as a foundation for managing the environmental impact of road salts. (Environment Canada 2004; 2006b; Environment Canada and Health Canada 2001; The City of Calgary 2009)

While “Codes of Practice” provide a foundation for safely managing the mixing, storing, transport and application of salts, naturally occurring salts can compound the effects. Thus it is important to account for the background concentrations of the elements of concern. Naturally occurring soluble salts present in Alberta soils consist of various combinations of sodium ( $\text{Na}^+$ ), magnesium ( $\text{Mg}^{2+}$ ) and calcium ( $\text{Ca}^{2+}$ ) with chloride ( $\text{Cl}^-$ ), sulphate ( $\text{SO}_4^{2-}$ ) and bicarbonate ( $\text{HCO}_3^-$ ). (AENV 2001b; Richards et al. 1954) Alberta Environment states that sodium and magnesium sulphates are the most common naturally occurring salts on the Canadian Prairies with sodium sulphate dominating in southern Alberta. (AENV 2001b)

Soils classified as saline contain sufficient amounts of soluble salts that can produce harmful effects to plants by increasing the salt content of the soil which in turn changes the osmotic pressure of the soil and thereby reduces a plant’s capacity for water uptake. Chloride ions are considered to be a micronutrient and an essential element for many plant functions, including maintaining osmotic balance. Most soil chloride is found dissolved in the soil water and it is extremely mobile. Too much chloride can produced effects similar to salt damage, and too little can result is reduced nutrient uptake. When sodium salts dominate, the potential exists for increased ion exchange with the sodium resulting in displacement of other metals in the soil. These types of soils are often classified as sodic. The pH is generally less than 8.5 for saline soils and greater than 8.5 for alkali/sodic soils. (AENV 2001b; Environment Canada 2006b; Richards et al. 1954)

Based on the above information three(3) attributes have been selected for estimating the effects of the road salts applications on the environment are (1) Sodium Adsorption Ratio (SAR) and (2) electrical conductivity (EC) and (3) pH. These attributes are evaluated and transformed to a “Level of Concern” value between 0.000 and 1.000 based on the criteria identified for each. The  $\text{SE}_{\text{ECOL}}$  will be an average of the available transformed

values. If sufficient data is not available for evaluation of an attribute, the  $SE_{ECOL}$  will be based on those that are. For example, if data is not available to evaluate the SAR attribute but there is data for the remaining two, the average will be taken out of two and a note will be placed in the “Comments” column indicating data insufficiency. This may influence the rank position of the site, and the decision makers need to be aware of this when prioritizing the actions to be taken with the ranked sites.

**Equation 5–30: Estimated Salinity Effect ( $SE_{ECOL}$ )**

$$SE_{ECOL} = \frac{SAR_{ECOL} + EC_{ECOL} + pHF_{ECOL}}{N}$$

where,

|              |   |   |
|--------------|---|---|
| N            | = | Number of attributes to be considered (max = 3) |
| $SAR_{ECOL}$ | = | Sodium Adsorption                               |
| $EC_{ECOL}$  | = | Electrical Conductivity                         |
| $pHF_{ECOL}$ | = | pH Factor                                       |

#### 5.4.3.5.1 Sodium Adsorption Ratio (SAR)

The principal inorganic ionic components of soil include calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, fluoride and nitrate. The condition of the soil is generally determined based on a ratio of these ions in soil water (Richards et al. 1954). Sodium is highly water soluble and readily sorbs to soil particles. However, under conditions of high leachability and poor/low sorption, the sodium can infiltrate groundwater systems and/or be transported to surface water bodies (Environment Canada and Health Canada 2001).

Sodium levels in soils are often reported as the sodium adsorption ratio (SAR). The SAR is a measure of the sodicity of the soil and is evaluated as a ratio of water soluble sodium to water soluble calcium and magnesium in the soil (Fetter 1999). In soils with SAR's greater than 1, the sodium remains in a hydrated form and tends to separate the individual soil particles, a



process known as dispersion. Dispersed soils are sticky when wet, can form crusts through evaporative processes restricting water infiltration (impermeable to rain) and become very hard when dry. Water and air movement through the soil are restricted and when combined with elevated sodium levels significantly affect plant growth and survival. The higher the proportion of sodium identified, the greater the hazard to aquatic and terrestrial biota.

Hazard ranges for SAR's reported in literature tend to overlap; values between 2 and 20 reflect a low hazard; values between 7 and 18 are medium hazards; high hazards have SAR's between 11 and 26, and very high hazards above that (Fetter 2001; Richards et al. 1954). Alberta Environment provides generic guidelines for salt contamination assessments which are considered to be protective based on land use designations and soil stratum (topsoil, subsoil). The hazard divisions are within those boundaries found in literature. Remediation to the guideline levels is required to a depth at which similar levels of naturally occurring salts occur or to the base of the rooting zone, whichever is greater.(AENV 2001b) The SAR values provided for unrestricted land used are the same regardless of the soil stratus and thus are used as guidelines for identifying the SAR<sub>ECOL</sub> "Level of Concern" boundaries.

When assessing Commercial/Industrial properties, the SAR value provided by Alberta Environment is much more tolerant but, in return, places restrictions on the future use of that property; the property must remain zoned for commercial/industrial use. As the property and land use designations for the subject site and neighboring sites are known through the Level 3 MODM screening process, the commercial/industrial SAR criteria will only be used if all these properties are zoned commercial or industrial as it is unlikely (not improbable) that the subject property would be rezoned to one more sensitive placing into the unrestricted land use classification. If however, any one of the properties (subject or neighboring) are zoned other than commercial or industrial the more restrictive SAR classifications will be used. As some areas may have elevated background values, these can be taken into account at the screening level. If no background data is available, then general values based on the Alberta Soil and Groundwater Remediation Guidelines will be used.

The  $SAR_{ECOL}$ , is a comparative measure of the site specific quantity (less background quantity) to the guidance value (Equation 5–31).

**Equation 5–31:  $SAR_{ECOL}$**

$$SAR_{ECOL} = SAR_{MEASURED} - SAR_{BACKGROUND}$$

where,

|              |   |   |
|--------------|---|---|
| $SAR_{ECOL}$ | = | Sodium Adsorption Ratio (unitless)                      |
| MEASURED     | = | Site specific concentration/value                       |
| BACKGROUND   | = | Site specific or general background concentration/value |

The  $SAR_{ECOL}$  derived from the above equation is then transformed according to the appropriate “Level of Concern” equations provided in Table 5-34.

**Table 5-34: SAR Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE           | $SAR_{ECOL-NOMINAL}$           | $SAR_{ECOL-TRANSFORMED}$                          |
|------------------|-----------------------|--------------------------------|---|
| Low              | $0.0 \leq x \leq 0.4$ | $SAR_{ECOL-N} < 4.0$           | $SAR_{ECOL-T} = 0.000$                            |
|                  |                       | $4.0 \leq SAR_{ECOL-N} < 6.0$  | $SAR_{ECOL-T} = (2.000E-01) SAR_{ECOL-N} - 0.800$ |
| Medium           | $0.4 < x \leq 0.6$    | $6.0 \leq SAR_{ECOL-N} < 8.0$  | $SAR_{ECOL-T} = (1.000E-01) SAR_{ECOL-N} - 0.200$ |
| High             | $0.6 < x \leq 1.0$    | $8.0 \leq SAR_{ECOL-N} < 12.0$ | $SAR_{ECOL-T} = (1.000E-02) SAR_{ECOL-N} - 0.200$ |
|                  |                       | $12.0 \leq SAR_{ECOL-N}$       | $SAR_{ECOL-T} = 1.000$                            |

If the zoning is commercial/industrial, then the  $SAR_{ECOL}$  is transformed according to Table 5-35 wherein the boundaries are adjusted based on the recommended soil quality guideline value for commercial and industrial land uses and the aforementioned literature

values. The recommended SAR value of 12.0 is placed in the middle of the medium “Level of Concern” category.

**Table 5-35: SAR Transformation Equations - Commercial/Industrial Zone**

| LEVEL OF CONCERN | VALUE RANGE           | SAR <sub>ECOL-NOMINAL</sub>                  | SAR <sub>ECOL-TRANSFORMED</sub>   |
|------------------|-----------------------|--|---|
| Low              | $0.0 \leq x \leq 0.4$ | $\text{SAR}_{\text{ECOL-N}} < 4.0$           | $\text{NA}_T = 0.0$   |
|                  |                       | $4.0 \leq \text{SAR}_{\text{ECOL-N}} < 7.0$  | $\text{SAR}_{\text{ECOL-T}} = (1.333\text{E-}01) \text{SAR}_{\text{ECOL-N}} - 0.5333$ |
| Medium           | $0.4 < x \leq 0.6$    | $7.0 \leq \text{SAR}_{\text{ECOL-N}} < 18.0$ | $\text{SAR}_{\text{ECOL-T}} = (1.818\text{E-}02) \text{SAR}_{\text{ECOL-N}} + 0.273$  |
| High             | $0.6 < x \leq 1.0$    | $18 \leq \text{SAR}_{\text{ECOL-N}} < 26.0$  | $\text{SAR}_{\text{ECOL-T}} = (5.000\text{E-}02) \text{SAR}_{\text{ECOL-N}} + 0.300$  |
|                  | $0.0 \leq x \leq 0.4$ | $26.0 \leq \text{SAR}_{\text{ECOL-N}}$       | $\text{NA}_T = 1.0$   |

The transformation equation were obtained from the following graphical representations:

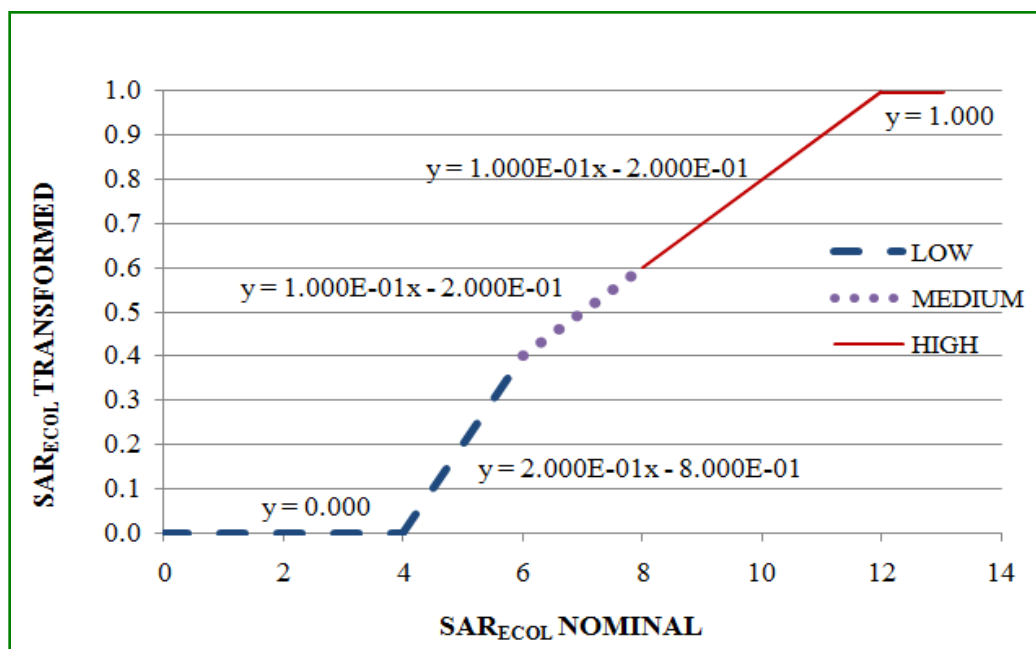


Figure 5—17: SAR Transformation Equation

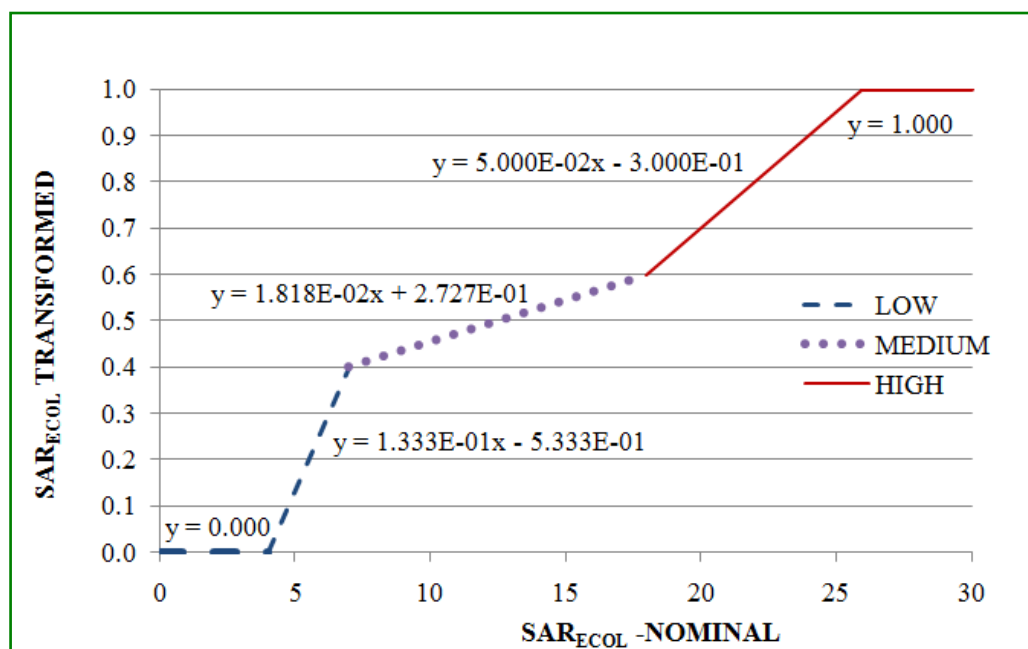


Figure 5—18: SAR Transformation Equation (Commercial/Industrial)

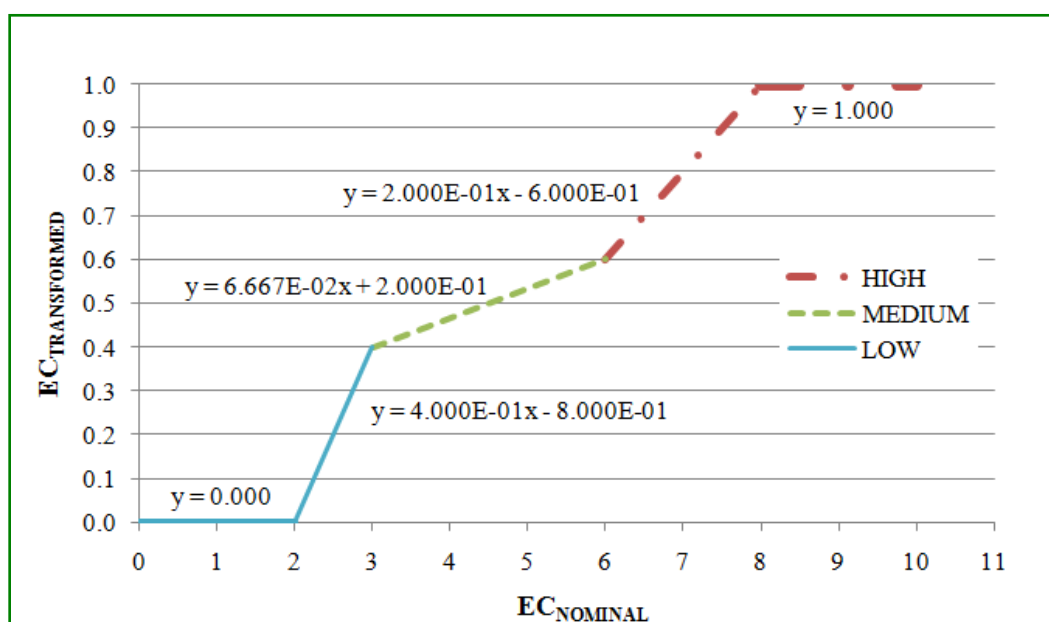
#### 5.4.3.5.2 Electrical Conductivity (EC)

Wherein the quantities of specific elements such as sodium and chloride are readily measureable through chemical analyses, the ions in solutions are measured based on their ability to conduct a current. This is the most effective means of identifying the potential for adverse effects of sodium on soil. The electrical conductance, EC, of a solution is attributed to the total concentration of all cations and anions in solution and is used to express the total dissolved salt concentration present. (AENV 2001b; Fetter 1999) The salt content of the soil can be estimated by measuring the electrical conductivity in a saturated soil paste, a more dilute suspension of soil in water, or directly from a water extract of the soil (Richards et al. 1954). Regardless of the method, the current is generated via movement of ions in solution. As the ion concentration increase, movement increases resulting in a higher electrical conductivity measurement. Electrical conductivity is reported in terms of deci-Siemens per meter (dS/m).

Alberta Environment provides generic guidelines for salt contamination assessments which are considered to be protective based on land use designations and soil stratum (topsoil, subsoil)(AENV 2001b; 2008b). The EC values provided for unrestricted land use are more restrictive for upper soil stratum (topsoil) than for the lower. The topsoil environment is critical for the majority of plants as the majority of their roots are typically within this zone. Thus, in order to be protective of this region, the rating categories provided for topsoil are used as guidelines for identifying the EC “Level of Concern” boundaries. As with the SAR values, Environment Canada provides a separate guideline value for properties zoned commercial or industrial but this value fall within the middle of the *medium* “Level of Concern” and thus the transformation equations derived Table 5-36 can be universally applied.

**Table 5-36: Electrical Conductivity Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE               | EC <sub>NOMINAL</sub>              | EC-TRANSFORMED                                      |
|------------------|---------------------------|------------------------------------|---|
| Low              | $0.000 \leq x < 0.400$    | $EC_{L\text{NOM}} < 2.00$          | $EC_T = 0.0$  |
|                  |                           | $2.00 \leq EC_{\text{NOM}} < 3.00$ | $EC = (4.00\text{E-}01) EC_{\text{NOM}} - 0.800$    |
| Medium           | $0.400 \leq x < 0.600$    | $3.00 \leq EC_{\text{NOM}} < 6.00$ | $EC_T = (6.667\text{E-}02) EC_{\text{NOM}} + 0.200$ |
| High             | $0.600 \leq x \leq 1.000$ | $6.00 \leq EC_{\text{NOM}} < 8.00$ | $EC_T = (2.000\text{E-}01) EC_{\text{NOM}} - 0.600$ |
|                  | $1.000 \leq x$            | $8.00 \leq EC_{L\text{NOM}}$       | $EC_T = 1.0$  |

**Figure 5—19: EC Transformation Equation**

#### 5.4.3.5.3 pH Factor ( $\text{pH}_{\text{FCOL}}$ )

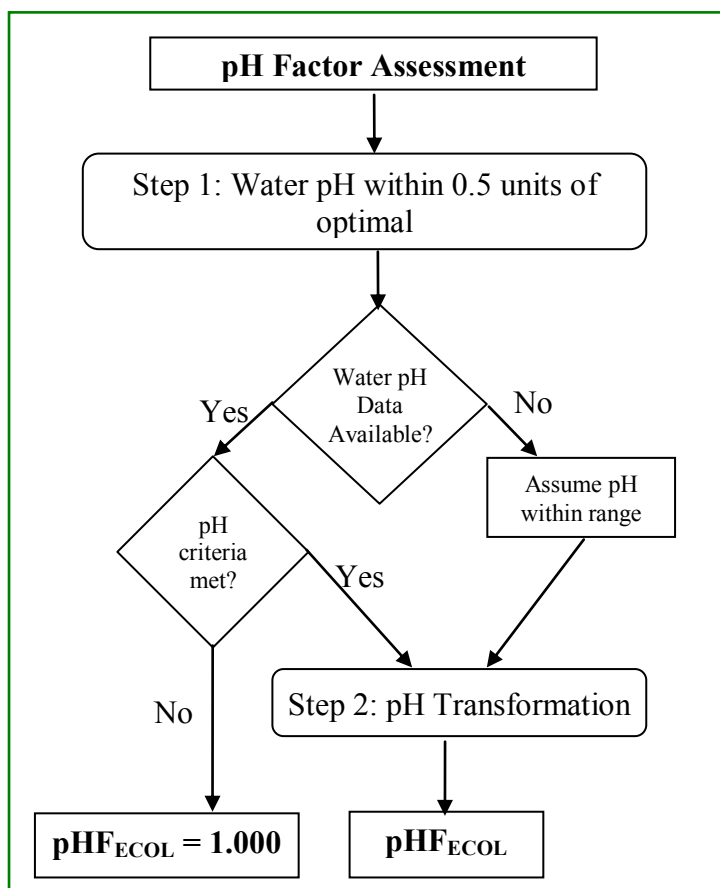
The pH value of an aqueous solution is defined as the negative logarithm of the hydrogen-ion activity. It is dependent on the characteristics of the soil such as the composition of exchangeable cations (positively charged ions), the composition and concentration of soluble salts and the presence or absence of gypsum and alkaline-earth carbonates.(Richards et al. 1954) A pH measurement reveals if a solution is acidic or alkaline. The pH scale extends from 0.0 to 14.0 with 7.0 being neutral. The lower values indicate acidic environments, and the higher, alkaline. If there are equal amount of acidic and alkaline molecules, the pH is considered to be neutral.

Soil pH affects the availability of nutrients to plants and each plant has its own recommended soil pH value range. The same is true for organisms in aquatic environments. The synergistic effects of pH are, however, more of concern. The use of road salts disrupts the mineral inorganic fraction of roadside soils. The degree of salt exposure of the soil controls the degree of pH change through changes in the concentration of cations on cation exchange sites and in soil solution and overall ion concentrations. Shifts in pH may be induced by sodium displacing hydrogen ions from cation exchange sites. Magnesium and calcium present in commercial road salts can also induce similar ionic displacements.(Green et al. 2008) A site with a high cation exchange capacity takes a longer time to acidify but it also takes longer to recover. An increase in cations into the environment results in an increase in the pH (more alkaline). A decrease in the pH of an environment can result in chemical changes which may make an element/substance more hazardous than normal (e.g. aluminum, lead or mercury) and reduce an organisms' ability to survive even if the pH level is within its acceptable range. Soils within the Canadian Prairies range from neutral to alkaline where the soil are naturally salt enriched. (Environment Canada and Health Canada 2001) Optimal values for most plants are between 6.0 and 7.5. Saline-sodic soils are often characterized by  $\text{pH} > 8.5$ (AENV 2001b). The toxicity to aquatic life of some substances is affected by pH. According to Alberta Environment's Surface Water Quality Guidelines(AENV 1999), the

pH of water should be within the range of 6.5 to 8.5 and never differ by more than 0.5 from background levels.

The pH values in the Phase II Site Assessment investigations are provided as either a single value or multiple values from several samples. The user-form developed for soil and groundwater chemistry enables the user to enter the minimum, maximum and background values available for the site. If only a single value is available for entry, min and max values are considered the same. If background values are not available, then optimal values will be assumed. In order to be protective of both terrestrial and aquatic biota, the optimal pH range will be considered to be between 6.5 and 7.5 (common range).

The  $\text{pHF}_{\text{ECOL}}$  will be evaluated through a two step process (Figure 5—20).





**Figure 5—20: pH Factor Assessment Flowchart**

The *first step* involves the verification of water pH range. As stated above, the water guidelines stipulate that the pH of surface water should never differ by more than 0.5 from background levels. This shall be considered to be applicable to groundwater sampling at the sites. If water data is not available, the criteria shall be assumed to be satisfied and the  $\text{pHF}_{\text{ECOL}}$  evaluation process will continue to the next step. If data is available the minimum and maximum values will be compared with the background minimum and maximum values. If either of these differ by 0.5 units or more then the  $\text{pHF}_{\text{ECOL}}=1.00$ , otherwise the process will continue to the next step. If background data is unavailable, the optimal range will be used.

The second step involves the transformation of site specific pH values into “Levels of Concern”. Using the optimal pH range and the saline-sodic pH values as basis for comparison, if the minimum and maximum values are within the optimal pH range selected, the potential hazard associated is null (0.0). If one of the values is within range and the other not, the value that is outside the range is transformed according to the transformation equations in Figure 5—21 and Table 5-37.

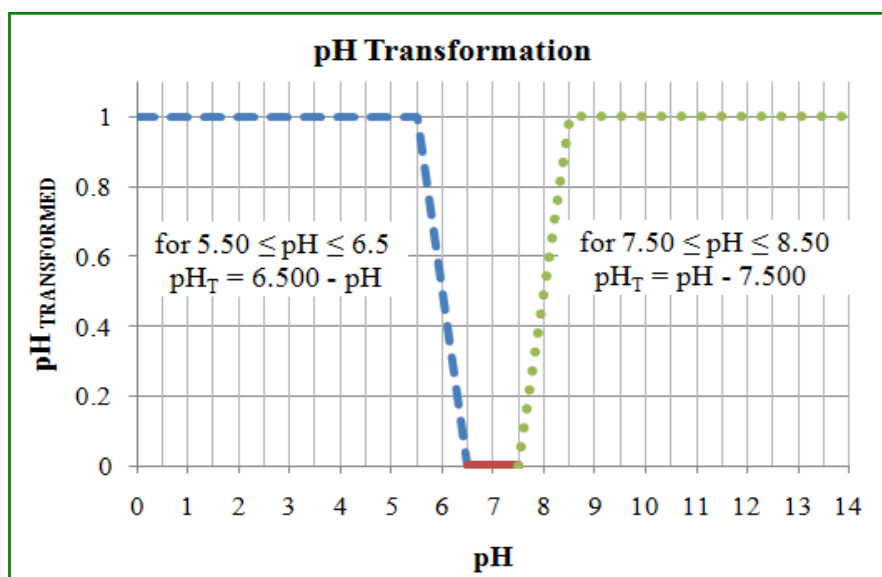


Figure 5—21: pH Transformation Equation

**Table 5-37: pH Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE         | $\text{pH}_{\text{NOMINAL}}$                 | $\text{pH}_{\text{TRANSFORMED}}$               |
|------------------|---------------------|--|--|
| Low              | $x = 0.000$         | $6.50 \leq \text{pH}_{\text{NOM}} < 7.50$    | $\text{pH}_T = 0.00$                           |
| Medium           | $0.000 < x < 1.000$ | $5.50 \leq \text{pH}_{\text{NOM}} \leq 6.50$ | $\text{pH}_T = 6.500 - \text{pH}_{\text{NOM}}$ |
|                  |                     | $7.50 \leq \text{pH}_{\text{NOM}} \leq 8.50$ | $\text{pH}_T = \text{pH}_{\text{NOM}} - 7.500$ |
| High             | $1.000 \leq x$      | $\text{pH}_{\text{NOM}} < 5.50$              | $\text{pH}_T = 1.00$                           |
|                  |                     | $8.50 < \text{pH}_{\text{NOM}}$              |  |

The  $\text{pHF}_{\text{ECOL}}$  is then obtained by taking the maximum of the  $\text{pH}_T$  for the site specific minimum and maximum pH values. If both min and maximum values are outside the optimal range, both values are transformed using the appropriate equations and then averaged to obtain the  $\text{pHF}_{\text{ECOL}}$ .

In the case where data for both soil and groundwater are available, the  $\text{pHF}_{\text{ECOL}}$  is evaluated for each and the largest value is selected as indicative of the potential hazard associated with this site for this attribute.

**Equation 5-32: pH Factor ( $\text{pHF}_{\text{ECOL}}$ )**

IF  $(/PHMIN_{BKGD} - PHMIN/) \geq 0.5$  OR  $(/PHMAX_{BKGD} - PHMAX/) \geq 0.5$  THEN

$$\text{pHF}_{\text{ECOL}} = 1.000$$

ELSE

$$\text{pHF}_{\text{ECOL}} = \max \left[ \left( \frac{(\text{pH}_{T-\text{MIN}} + \text{pH}_{T-\text{MAX}})}{2} \right)_{\text{SOIL}}, \left( \frac{(\text{pH}_{T-\text{MIN}} + \text{pH}_{T-\text{MAX}})}{2} \right)_{\text{WATER}} \right]$$

where,

$\text{pHF}_{\text{ECOL}}$  = pH Effect

$\text{PHMIN}_{\text{BKGD}}$  = Minimum background pH (water)

|   |   |   |
|---|---|---|
| $\text{PHMAX}_{\text{BKGD}}$                          | = | Minimum background pH (water)             |
| $\text{PH}_{\text{MIN}},$<br>$\text{PH}_{\text{MAX}}$ | = | Nominal water pH (minimum and maximum)    |
| $\text{PH}_{\text{T-MAX}}$                            | = | Transformed Minimum pH “Level of Concern” |
| $\text{PH}_{\text{T-MIN}}$                            | = | Transformed Maximum pH “Level of Concern” |

Once the final value is obtained for the  $\text{PHF}_{\text{ECOL}}$ , the Level of Concern can be interpreted based on the ranges stipulated in Table 5-38.

**Table 5-38: pH Factor Level of Concern**

| LEVEL OF CONCERN | $\text{PHF}_{\text{ECOL}}$ |
|------------------|----------------------------|
| Low              | $0.000 \leq x \leq 0.400$  |
| Medium           | $0.400 \leq x \leq 0.700$  |
| High             | $0.700 \leq x \leq 1.000$  |

#### ***5.4.4 Potential Political Impact Factor (PPIF) Evaluation***

The political impact of a potentially contaminated site is measured by several factors such as the onsite activity, proximity to sensitive areas (schools, hospitals, daycares, bird sanctuary, fish hatchery, senior’s lodges, etc), mode of transport into the environment, nature of contamination, extent of contamination, and public perception. A number of these have already been addressed through the Potential Human Impact and Ecological Impact Factors, leaving onsite activity, proximity to sensitive areas, and public perception to be examined.

The common element throughout the remaining factors is public perception. Heightened public concern is always associated with an event that has occurred or continues to occur on the subject site and its perceived potential human and ecological impact. Therefore, the Potential Political Impact Factor (PPIF) is designed to address this issue by

accounting for the potential hazard associated with the onsite activity/activities and the impact to the surrounding area(s).

The identification of sensitive areas and their proximity to the site of concern would be beneficial in the PPIF assessment by enhancing the site description. However, the time involved in collecting such data may not be feasible due to the budgetary constraints of the municipality. An alternative means of representing proximity to sensitive areas is through the use of land and property use designations for a given site and its neighboring sites since the zoning for a property dictates the activities allowed and, hence, controls the land and property usage.

The PPIF is derived from the arithmetic average of two equally contributing factors: an Onsite Activity Factor ( $OAF_{ECOL}$ ) and a Land and Property Use Factor ( $LPF_{ECOL}$ ).

**Equation 5–33: Potential Political Impact Factor (PPIF)**

$$PPIF = \frac{OAF_{ECOL} + LPF_{ECOL}}{2}$$

where,

$OAF_{ECOL}$  = Onsite Activity Factor (max = 1.000)

$LPF_{ECOL}$  = Land and Property Use Factor (max = 1.000)

#### 5.4.4.1 Onsite Activity Factor ( $OAF_{ECOL}$ )

In the Level 1 Model screening protocol, potentially contaminating activities for each subject site were identified and classified into two categories; high risk (PCA1, Tank1, Foreign Utility Well) and medium risk (PCA2, Tank2, Foreign Utility Pipeline) with assigned default risk weights of 1.0 and 0.6, respectively. These risk weights were the upper-most values of the *medium* and *high* categories.

During the Level 1 screening, the total number of above-ground storage tanks and underground storage tanks associated with the site (current and historical) were identified and recorded along with onsite potential contaminating activities, in decreasing order of “risk

(The City of Calgary 2006). The classification scheme used is based on the scheme developed for the Level 1 Rule-Based System (Table 4-3 and Table 4-6).

Modifications are made only with respect to the tank terminology. Tanks were identified as high perceived risk (Tank 1 = underground storage tanks and/or unknown storage tanks, and underground and above ground storage tanks) and medium risk tanks (Tank 2 = above ground storage tanks only). The *Tank1* and *Tank2* designations will not be used but rather UUST (underground and/or unknown storage tanks) and AST (above ground storage tanks) with potential risk weights of 1.0 and 0.6, respectively. The weights selected are the upper-most values in the *high* and *medium* risk weight categories. The change in designation is required to account for the number of tanks associated with the site under investigation.

The  $OAF_{ECOL}$  is evaluated as the normalized resultant of three components: Tanks, PCA's, and Foreign Utility Services (wells/pipelines).

**Equation 5–34: Onsite Activity Factor ( $OAF_{ECOL}$ )**

$$OAF_{ECOL} = \frac{TC_{ECOL} + PCA_{ECOL} + FUS_{ECOL}}{N}$$

where,

$OAF_{ECOL}$  = Onsite Activity Factor (max = 1.000)

N = Total Maximum “weight” for Onsite Activities

$TC_{ECOL}$  = Tank Component (max = 1.600)

$PCA_{ECOL}$  = Potentially Contaminating Activity Component

$FUS_{ECOL}$  = Foreign Utility Service Component(max = 1.600)

#### 5.4.4.1.1 Tank Component ( $TC_{ECOL}$ )

The tank component is derived by summation of the “Level of Concern” values associated with the type of tanks present ONSITE.

**Equation 5–35: Tank Component (TC<sub>ECOL</sub>)**

$$TC_{ECOL} = \sum_{i=1}^n TANK_{TRANSFORMED}$$

$$= AST_T + UUST_T$$

where,

AST<sub>T</sub> = Transformed Aboveground storage tank *Level of Concern* (max = 0.6)

UUST<sub>T</sub> = Transformed Underground / Unknown storage tank *Level of Concern*  
(max = 1.0)

The Transformed *Level of Concern* values are determined based on the type of tank (AST, UUST), the number of tanks, the associated risk classification (medium, high) and validation of one(1) of three(3) IF-THEN rules:

Rule 1: IF there are zero(0) tanks of a given type

THEN the transformed *Level of Concern* = 0.00.

Rule 2: IF there are more than ten(10) tanks of a given type

THEN the transformed *Level of Concern* = maximum for  
the associated value range (med = 0.7, high = 1.0)

Rule 3: IF there are between one(1) and five(5) tanks, or six(6) and ten(10) tanks

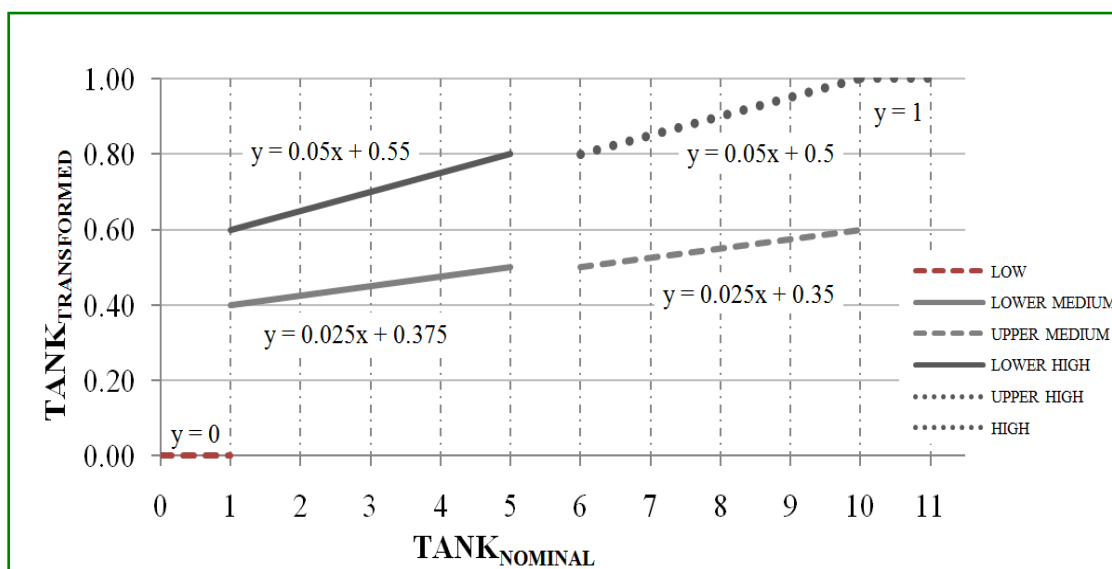
THEN the transformed *Level of Concern* = value based on a linear  
transformation equation for the associated value range

The boundaries of 5 and 10 tanks were selected based on the more than 600 Level 1 screened sites; # AST = 0 to 6, #UST's and unknown tanks = 0 to 11. These rules are summarized in Table 5-39 and Table 5-39 and the transformations equations illustrated in Figure 5—22.

Based on this scoring system, the maximum value that can be obtained for the tank component is 1.60; 0.60 for AST's and 1.00 for UUST's.

**Table 5-39: Storage Tank Transformation Equations**

| LEVEL OF CONCERN | VALUE RANGE             | TANK <sub>NOMINAL</sub>     | TANK <sub>TRANSFORMED</sub>               |
|------------------|-------------------------|-----------------------------|---|
| Low              | $0.00 \leq x \leq 0.40$ | $AST_{NOM} < 1$             | $AST_T = 0.00$                            |
|                  |                         | $UUST_{NOM} < 1$            | $UUST_T = 0.00$                           |
| Medium           | $0.40 \leq x \leq 0.50$ | $1 \leq AST_{NOM} \leq 5$   | $AST_T = (2.500E-02) AST_{NOM} + 0.375$   |
|                  | $0.50 \leq x \leq 0.60$ | $6 \leq AST_{NOM} \leq 10$  | $AST_T = (2.500E-02) AST_{NOM} + 0.350$   |
|                  |                         | $10 \leq AST_{NOM}$         | $AST_T = 0.700$                           |
| High             | $0.60 \leq x \leq 0.80$ | $1 \leq UUST_{NOM} \leq 5$  | $UUST_T = (5.000E-02) UUST_{NOM} + 0.550$ |
|                  | $0.80 \leq x \leq 1.00$ | $6 \leq UUST_{NOM} \leq 10$ | $UUST_T = (5.000E-02) UUST_{NOM} + 0.500$ |
|                  |                         | $10 \leq UUST_{NOM}$        | $UUST_T = 1.00$                           |

**Figure 5—22: Tank Transformation Equations**



#### 5.4.4.1.2 Potentially Contaminating Activity Component ( $PCA_{ECOL}$ )

During the Level 1 screening process, a feasible number of potentially contaminating activities were identified for each property/site, in decreasing order of perceived risk. The  $PCA_{ECOL}$  is based on these entries and their associated risk level. According to Table 4-6, the activities are classified as either as *high* or *medium* risk and were originally assigned default risk weights of 1.0 and 0.6, respectively. These default values will continue to be used to maintain consistency between the Model Framework levels.

The  $PCA_{ECOL}$  is derived from a summation of the “weight” assigned to the activities identified for the site under review. As the number of entries that can include *high* risk activities is dependent upon the number of activities the Municipality decides to screen, the maximum score available for the  $PCA_{ECOL}$  is equal to the total number identified. For example, if four (4) activities are identified, the maximum value of  $PCA_{ECOL}$  is 4.0; if six (6) activities are identified, the maximum  $PCA_{ECOL}$  value is 6.0.

#### Equation 5–36: Potentially Contaminating Activity Component ( $PCA_{ECOL}$ )

$$PCA_{ECOL} = \sum_{i=1}^n PCA_{WEIGHT}$$

where,

i = Number of Potentially Contaminating Activities identified

$PCA_{WEIGHT}$  = *Risk* weight associated with Potentially Contaminating Activity

#### 5.4.4.1.3 Foreign Utility Service Component ( $FUS_{ECOL}$ )

The  $FUS_{ECOL}$  is derived similar to the  $PCA_{ECOL}$ . It is the sum of the *risk* weights associated with the presence of a Foreign Utility Well or Foreign Utility Pipeline, but the quantity is either zero or one. Thus, using the classification specified in Table 4-6 and the default *risk* weights, the maximum value attainable for the  $FUS_{ECOL}$  is 1.60.

**Equation 5–37: Foreign Utility Service Component ( $FUS_{ECOL}$ )**

$$FUS_{ECOL} = FUW_{WEIGHT} + FUP_{WEIGHT}$$

where,

$FUW_{WEIGHT}$  = “Risk” weight associated with presence of Foreign Utility Well  
(max = 1.0)

$FUP_{WEIGHT}$  = “Risk” weight associated with presence of Foreign Utility Pipeline  
(max = 0.6)

#### 5.4.4.2 Land and Property Use Factor ( $LPF_{ECOL}$ )

Heightened public concern is based on the perceived harm to a surrounding community (receptor) due to an activity occurring on a particular site. Wherein the activities of potential concern have been accounted for in the  $OAF_{ECOL}$ , the  $LPF_{ECOL}$  focuses on the perceived harm to the sensitive receptors in the surrounding community. In order to streamline the data collection associated with a site regarding possible sensitive receptors, property zoning (land and property use designations) will be used. The type of sensitive receptors that may be present at a given location is dictated by the activities permitted by the zoning categories defined by the Municipality (The City of Calgary 2008 (May 2010 Update)-a; b).

In the Level 1 Model protocol, non-prioritized land and property use designations were identified and weight/risk rankings were assigned based on source and receptor propensity. In the Level 1 Model, the highest source and receptor weight assignment for the subject site was selected and used as indicative of the that site. The same procedure is to be used in the Level 3 Model protocol. The screening of land and property use designations now includes the neighboring sites and the same source and receptor weights developed for the Level 1 Model will be utilized. The generic hazard assignments (low-med-high) found in Table 4-9 and Table 4-10 were translated into numerical weights through the use of default values that the user could change at the time

of running the Level 1 Model. In order to maintain consistency with the weight assignments, the  $LPF_{ECOL}$  will reference the settings designated by the user.

Both land use and property use designations must be incorporated into the site score evaluation to effectively depict the usage; land use designations are reflective of the zoning, whereas property use is reflective of the actual activities occurring on the site. While property use and zoning designations for a given site may differ, both can have an impact on the sites status as a source of contamination or a receptor of offsite contamination sources. The  $LPF_{ECOL}$  is designed to capture the information.

When the potential human and ecological impact factors were evaluated the contributions from the subject site was set at 60% and each of the neighboring sites at 10%. The  $LPF_{ECOL}$  combines information from both subject and neighboring sites in equal contributions. The *Land Use Source* and *Receptor Factors* developed in the Level 1 protocol are used in the evaluation of the  $LPF_{ECOL}$ , with a slight modification to their application. These factors were originally designed to be applied to the subject site alone as information regarding neighboring properties was not collected in the Level 1 site screening. As that information is now available, the source equation will be used for the subject site and the receptor equation will be used for the neighboring sites. A further modification is the contribution from the property use and land use designations. In Level 1 the default contribution was 50%, and the user had the option of changing it as desired. For the purposes of the  $LPF_{ECOL}$ , the contributions are set at 50%. The equations are provided below:

**Equation 5–38: Land Use Source & Receptor Factors ( $LUSF$ ,  $LURF$ )**

$$LUSF = \frac{\text{Property Use Source Weight} + \text{Land Use Source Weight}}{2}$$

$$LURF = \frac{\text{Property Use Receptor Weight} + \text{Land Use Receptor Weight}}{2}$$

The  $LPF_{ECOL}$  is the arithmetic average of the Land and Property Use Source & Receptor Factors for the subject site and four (4) neighboring sites. As the maximum for each of these components is 1.0, the maximum value attainable for the  $LPF_{ECOL}$  is 1.0.

**Equation 5–39: Land and Property Use Factor ( $LPF_{ECOL}$ )**

$$LPF_{ECOL} = \frac{LUSF + \sum_{i=1}^4 LURF}{5}$$

where,

- i = neighboring sites ( north, east, south, west)
- LUSF = Land Use Source Factor (subject site ONLY)
- LURF = Land Use Receptor Factor (neighboring sites ONLY)

**5.4.5 Legislative Compliance Requirement Factor (LCRF)**

In the case where contamination has occurred to the extent that a regulatory body such as Alberta Environment has become involved, the decision to “clean-up” the property is no longer under the purview of the Municipality’s Environmental Manager. Mandatory action designated by a Regulatory Authority should be documented within the Level 3 MODM and be reflected in the final score. LCRF is designed as a Boolean factor to reflect this action. That is, it is a *yes (true)* or *no (false)* criterion wherein a value of 1.00 or null (0.00) is assigned, respectively. In the case of mandatory action, the site in question having undergone the Level 3 MODM screening, the LCRF would be administered to advance the specific site into the “Class A” category. If there is more than one site with action mandated by a Regulatory Authority, then those sites will ranked and cost estimates will be requested.

**5.4.6 Cost Impact Factor (CIF)**

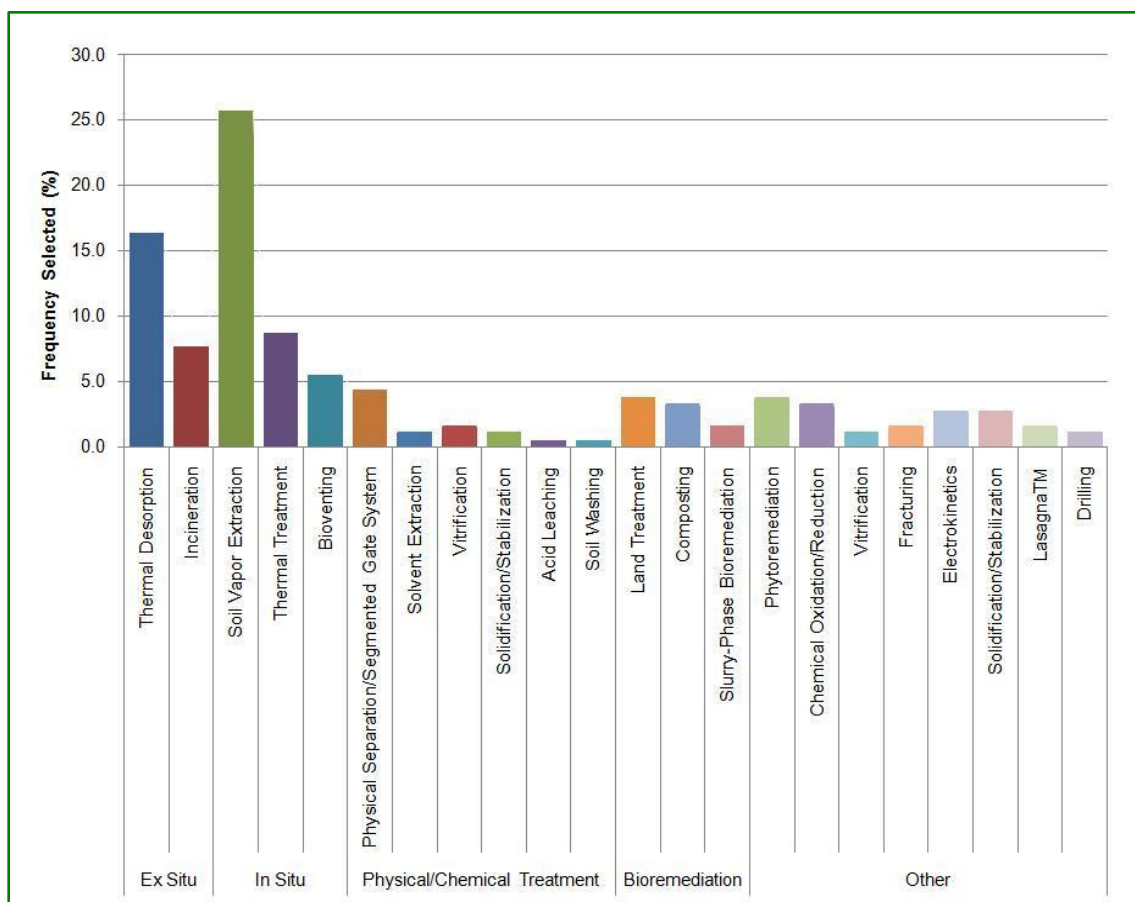
The Cost Impact Factor is a measure of the costs associated with remediation of a contaminated property. Costs are site specific and are contingent upon many factors. In order

to determine the overall potential cost of a site, selection of an appropriate remedial technology is required. Selection is based on several site specific features such as:

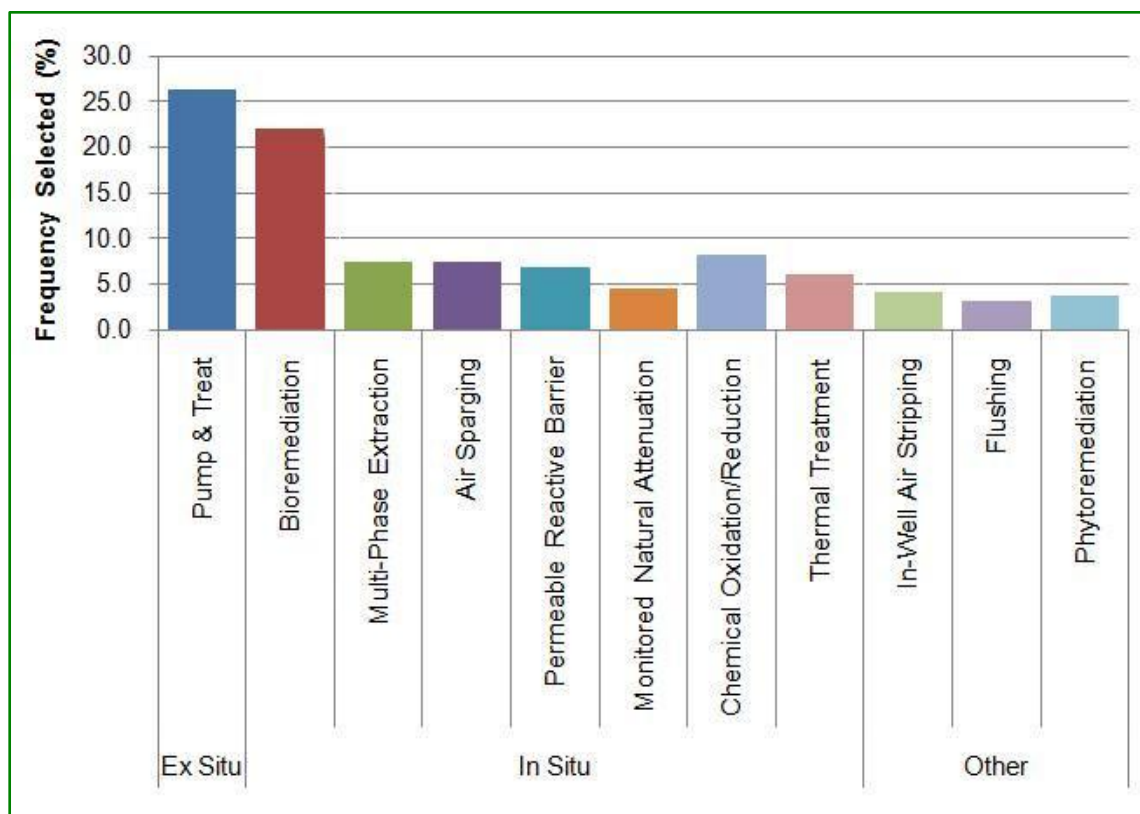
- the quantity, type and distribution of contaminant(s) to be treated
- the media to be treated (soil, sediment, surface water, groundwater)
- the soil type and properties (moisture content, porosity, organic content, etc.)
- the site hydrogeology, and
- the remediation endpoint required/desired,
- as well as balancing the following risks:
  - ecological with human
  - baseline contaminant with remedial, and
  - current with future land-use(s).

(Fiorenza et al. 2009; Kingscott and Weisman 2002; Suter et al. 2000).

There are several remediation technologies available for soil and groundwater treatment. A detailed analysis of each technology is required to determine which will best meet the goals of the site managers. The Federal Remediation Technology Roundtable is responsible for collecting case studies throughout the United States for the purpose of promoting the exchange of information regarding the development and use of technologies, and to identify and publicize more efficient, cost-effective methods of hazardous waste remediation (Federal Remediation Technologies Roundtable 1998). According to their most recent report, the most frequently selected soil remediation technology was In-Situ Soil Vapor Extraction (25.7%) followed by Ex-Situ Thermal Desorption (16.4%). The most frequent water remediation technology selected was In-Situ Bioremediation (62.7%) followed by Ex-Situ Pump & Treat (26.3%). The frequency of selection of alternative technologies are illustrated in Figure 5—23 and Figure 5—24 (Federal Remediation Technologies Roundtable 2006).



**Figure 5—23: Soil Remediation Technology Usage**



**Figure 5—24: Water Remediation Technology Usage**

There are two types of costs that need to be considered when evaluating the potential of a specific remedial action: primary and secondary. Primary costs refer to the baseline costs of implementing a specific technology whereas secondary costs refer to the possible side-effects of its implementation. A listing of primary and secondary costs is provided in Table 5-40.

**Table 5-40: Technology Cost Summary**

| TECHNOLOGY           |                                    | COST (\$US PER UNIT) |                | NOTES   |
|----------------------|------------------------------------|----------------------|----------------|---|
| Bioremediation       | ex-situ (soil)                     | 17 – 1596            | m <sup>3</sup> |   |
|                      | in-situ (soil)                     | 226 – 432            | m <sup>3</sup> |   |
|                      | in-situ (Groundwater)              | 379 – 383            | m <sup>3</sup> |   |
| Bioventing           | < 7645 m <sup>3</sup>              | 8 – 435              | m <sup>3</sup> | Unit costs decrease as larger quantities' treated                           |
|                      | >7645 m <sup>3</sup>               | 2 – 26               | m <sup>3</sup> |   |
| Thermal Desorption   | < 9072 tonne                       | 37 – 615             | tonne          | Unit costs decrease as larger quantities' treated                           |
|                      | > 9072 tonne                       | 44 – 615             | tonne          |   |
| SVE                  | <7645 m <sup>3</sup>               | 42 – 1360            | m <sup>3</sup> | Unit costs decrease as larger quantities' treated                           |
|                      | >7645 m <sup>3</sup>               | 3 – 141              | m <sup>3</sup> |   |
| In-Situ Incineration | Solids                             | 474 – 1543           | tonne          | Unit costs decrease as larger quantities' treated                           |
|                      | Liquids                            | 2 – 6                | liters         |   |
| Pump & Treat         | Biological Treatment               | 28 – 444             | 1000 liters    | More expensive, alone, significantly less if combined with other treatments |
|                      | Granular Activated Carbon, GAC     | 2 – 383              | 1000 liters    | Dependent on contaminants and combination of treatments required            |
|                      | Physical/Chemical Removal of Metal | 10 – 225             | 1000 liters    | Used in combination with other treatments                                   |
|                      | Oxidation                          | 20 – 140             | 1000 liters    | \$56 for oxidation alone  |
|                      | Air Stripping                      | 1 – 383              | 1000 liters    | > \$130 with GAC  |



Although the individualized costs are listed, many projects often employ more than one technology in addition to several other actions to be undertaken. An example of this is the remedial action at the former Kingston Bell Park landfill in Kingston Ontario. Since 1997, the City of Kingston has spent over \$5 million on remedial actions at this particular site. A summary of some of the expenditures incurred are listed in Table 5-41 (City of Kingston).

**Table 5-41: Remediation Project Expenditures (Former Ontario Landfill)**

| ACTION   | STATUS    | COST(\$ CND) |
|--|-----------|--------------|
| Environmental Impact Study                     | Completed | 300,000      |
| Annual Monitoring                              | Ongoing   | 75,000       |
| Annual Leachate Collection System Maintenance  | Ongoing   | 220,000      |
| Wetland Treatment Feasibility Study            | Completed | 175,000      |
| Phreatophyte Tree Feasibility Study            | Ongoing   | 100,000      |
| PCB Assessment in Shallow Groundwater          | Completed | 145,433      |
| Nearshore Aquatic Effects Study                | Completed | 80,000       |
| Long-Term Management Options                   | Completed | 115,000      |
| Installation of Groundwater Collection Systems | Completed | 500,000      |
| Expansion of Groundwater Collection Systems    | Completed | 500,000      |
| Replacement of Clean Soil Cover                | Completed | 330,000      |
| System Upgrade                                 | Completed | 160,000      |
| Removal of Derelict Underground Infrastructure | Completed | 100,000      |
| Annual Shoreline Area Clean-up                 | Ongoing   | 30,000       |

The analysis and selection of appropriate technologies and determination of the associated costs are beyond the scope of this project. The decisions made in regard to appropriate remedial action(s) will be left under the purview of the consultants employed by the Municipality to perform the assessment. The Cost Factor will therefore be based on where estimated remedial costs identified by the Consultants fall within a select range of values and the associated “*Level of Concern*” transformation equations.

For the purposes of this project an estimate of the cost associated with remediation will be based on individual selected technologies and an estimated unit volume of contaminated media. Of the Phase II Environmental Site Assessment reports examined, the primary technologies suggested or employed included two of the FRTR’s most frequently selected, namely Soil-Vapor Extraction (SVE) and Pump-and-Treat(P&T), as well as two others; Physical Removal (“*Dig-and-Dump*”) and Monitoring. As FRTR provides the costs associated with the SVE and P&T remediation technologies, these will be used to establish the baseline boundary ranges for the CIF.

An arithmetic average of the cost ranges provided in Table 5-40 is derived and is considered to be representative of the remediation technology; assuming par currency value between U.S. and Canadian dollars.

Soil: SVE (\$72/m<sup>3</sup> for estimated impact volume >7500 m<sup>3</sup>;  
(\$700/m<sup>3</sup> for estimated impact volume < 7500 m<sup>3</sup>)

Ground Water: Pump & Treat (\$225/1000 liters)

These values will be applied to a site only if the media on-site has exceedances present. If soil exceedances were noted, the volume will be assumed to be equal to the product of the estimated impact surface area and the depth to groundwater. If exceedances were also noted in groundwater sampling, the volume of contaminated groundwater will be based on an assumed plume size equal to the estimated impact surface area used for the soil estimation and an approximate depth of 0.2 meters. Using the Level 3 testing database, the costs for SVE and P&T technologies were obtained and are presented in Table 5-42.

**Table 5-42: Remediation Technology Cost Estimate**

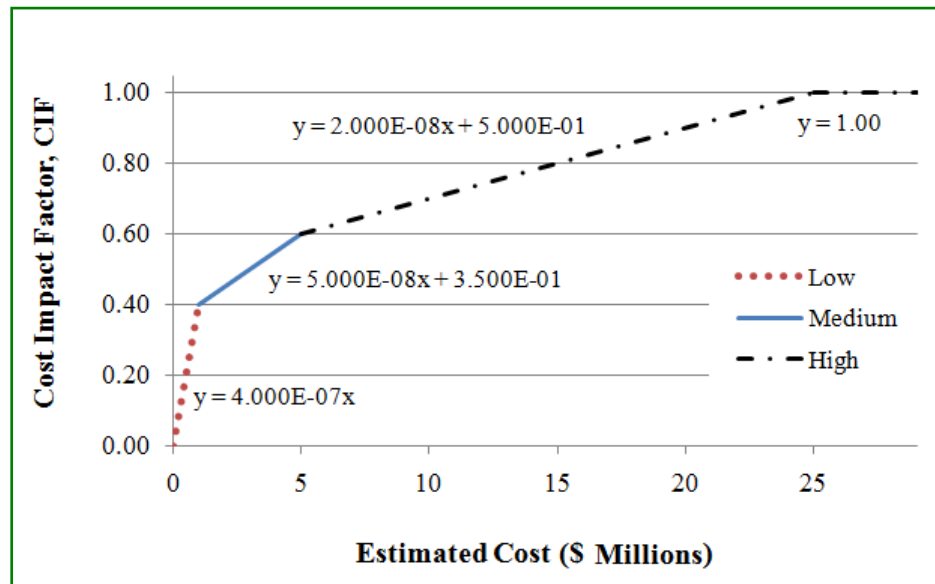
| REMEDICATION TECHNOLOGY     | MINIMUM COST | MAXIMUM COST   | AVERAGE COST  | OUTLIER REFERENCE VALUE * | NEAREST REAL COST | NEXT NEAREST COST |
|-----------------------------|--------------|----------------|---------------|---------------------------|-------------------|-------------------|
| Soil Vapor Extraction (SVE) | \$216,000    | \$96 million   | \$4.2 million | \$42 million              | \$36 million      | \$14 million      |
| Pump and Treat (P&T)        | \$3,600      | \$13.6 million | \$728,000     | \$7.6 million             | \$6.6 million     | \$4 million       |
| * Equation 4-17             |              |                |               |                           |                   |                   |

The minimum and maximum cost for remediation of these sites, taking into account the nearest and next nearest cost values to the outlier reference value, would be \$216,000 and \$42.6 million, respectively. While P&T is available at the lowest cost, groundwater remediation would not occur alone as contaminated soil above would be considered the primary source for contaminant transport to the water. As costs appear to be in the millions for remediation, the upper value for the *Low* Level of Concern is set at \$1million. The dataset shows a natural break at approximately the \$1 million mark for P&T and the \$5million mark for SVE (also the outlier modified average) which are used to form the lower and upper boundaries for the *Medium* Level of Concern. For the *High* Level of Concern Estimated Cost range, the critical boundary is set at the average of the nearest and next-nearest real SVE technology cost (\$25million).

Having identified the boundaries of the Levels of Concern for the Estimated Cost values, an estimated cost is prorated to a value between 0.00 and 1.00 using the appropriate CIF equations provided in Table 5-43. These equations are simple linear transformations of the estimated costs based on the low, medium and high category value ranges (Figure 5—25).

**Table 5-43: Cost Impact Factor**

| LEVEL OF CONCERN | VALUE RANGE           | ESTIMATED COST(X)                   | CIF                       |
|------------------|-----------------------|-------------------------------------|---------------------------|
| Low              | $0.0 \leq x \leq 0.4$ | $X < \$1,000,000$                   | $CIF = 4.000E-07X$        |
| Medium           | $0.4 < x \leq 0.6$    | $\$1,000,000 < X \leq \$5,000,000$  | $CIF = 5.000E-8x - 0.350$ |
| High             | $0.6 < x \leq 1.0$    | $\$5,000,000 < X \leq \$25,000,000$ | $CIF = 2.000E-8x - 0.500$ |
|                  |                       | $\$25,000,000 < X$                  | $CIF = 1.0$               |

**Figure 5—25: Estimated Cost Transformation Equation**

## 5.5 MODEL LIMITATIONS

During the development of Level 3 MCDM model of the DSS several assumptions were made that may contribute to certain limitations within the model:

1. The scoring system developed for this portion of the DSS produces an absolute rather than a relative score as each site is evaluated based on its own properties and not compared with other sites. Ranking is performed at the discretion of the decision maker after sites have been entered into the database and assessed. A means of isolating the top ranked sites for the assessment from further assessments has not been incorporated and thus these sites may change in position and urgency of action required.
2. The results of the Potential Human Impact factor assessment are contingent upon the assumption that the risks from simultaneous exposure to more than one carcinogenic substance are additive. The process assumes that the intakes are relatively small, that synergistic or antagonistic chemical interactions are occurring and that the mode of action and target organ of the substance are the same which is not always the case. The same argument holds for non-carcinogenic substances.
3. The evaluation of the Potential Ecological Impact factor relies on the use of the meadow vole as the sensitive receptor in the analysis. This small mammal was selected to simplify the process and reduce the costs involved in identifying the most sensitive organism of all of the organisms at risk for a given site. The meadow vole was selected based on the premise that small animals are typically maximally exposed to contaminants and thus would be protective for the majority of wildlife species (AENV 2009a; b) and that the toxicological data available for various chemicals are generally obtained from testing on rodents. However, the most susceptible organism may, in fact be missed.
4. The Potential Human and Ecological Impact factors are based on the human health and risk assessment paradigms and as such may imply a “risk” value in their evaluation. However, this is not the intent of the application. The model is

not intended to be nor should be used as a substitute for risk assessment. If a risk assessment is required for a particular site, a formal assessment should be obtained.

## **5.6 CASE STUDY**

The Level 3 MCDM model was applied to 20 sites spanning all quadrants of a municipality. Appendix C contains basic screening information regarding the spatial property descriptors, zoning review, hydrology, contaminating sources and activities, various site characteristics and Phase II test data results for each of the sites examined.

### ***5.6.1 Results & Discussion***

The final score, classification and rank for each of the sites are summarized in Table 5-44, along with the Potential Human, Ecological and Political Impact Factors. Table 5-45, Table 5-46, and Table 5-47 provide the intermediate component values obtained in the derivation of these impact factors. As no mandatory action was designated by a regulatory authority for any of the sites, the Legal Compliance Requirement Factors were assigned a value of 0.00. Evaluation of the Cost Impact factor is not included in this case study.

According to Table 5-44, the top four ranked sites (#1, #9, #22 and #23, respectively) are all within the medium *Level of Concern* as specified in Table 4-8 and are classified as either Class C or D. Comparison of these four sites reveals that the final score can be justified by examining the site order for each of the three impact factors.

The PHIF ranked these sites from highest to lowest as #1, #9, #23 and #22. The PHIF is based on the potential for human exposure to the various contaminants present at a subject site. The exposure, in turn, is dependent on the land/property use. Site #1 and #22 are at opposite ends of the spectrum; Site #1 being primarily commercial and Site #22 industrial. The overall % permeable groundcover is approximately equivalent for each of these sites but Site #1, being commercial, has the more sensitive receptor (child) associated with it and is therefore ranked higher. Sites #9 and #23 both have the same

overall receptors associated (child and adult) but the site #9 has a higher number of contaminants that can produce an adverse effect upon exposure. Therefore the ranking order obtained for the PHIF is acceptable.

The site rankings for the PEIF are #9, #22, #23, and #1. Site # 9 has the highest PEIF value due to ranking first in three of the seven sub-categories ( $EP_{ECOL}$ ,  $EB_{ECOL}$ , and  $SWP_{ECOL}$ ). Site #22 and #23 are tied with the frequency of first number rankings, but Site #22 has more second number rankings ( $IA_{EST}$ ,  $MGCP_{ECOL}$  and  $SWP_{ECOL}$ ). Site #1 is ranked last in this group with only one first place ranking ( $MGCP_{ECOL}$ ). Therefore, the order is correct.

The PPIF score ranks the sites from highest to lowest as 22, 1, 23 and 9. Site #22 has the highest number of activities and sources identified onsite and therefore should rank first in the PPIF (one PCA1, two PCA2, 5 high risk UUST's, 11 medium risk AST's). Of the top four sites, Site #1 would rank second due to the fact that it contains only high risk activities and sources onsite. Site #23 is next in ranking with a total of nine medium risk activities and sources identified. Site #9 has three high risk and three medium risk activities/sources identified but drops down in ranking due to the  $LPF_{ECOL}$  value being set at zero. The  $LPF_{ECOL}$  is based on the land use designation (i.e. property zoning) code and no code was listed during the screening process. Based on this examination, the results of the PPIF are validated.

When a parcel has had more than one report generated, the most recent report should take precedence in the ranking scheme. Site #1 and Site #18 are an example of this occurrence; two reports for the same site address spaced approximately two years apart. All things being equal at the site, the only way a different overall score could be achieved is through a change in the type and quantity of contaminants identified on the site. This is seen with Site #1 and #18. Site #1 is the most recent report for the property and ranked first overall in the case study, whereas #18 ranked 18th. The shift in position is attributed to an increase in the overall amount of toxic chemicals and an increase in groundwater contamination.

### ***5.6.2 Conclusion***

The Level 3 MCDM methodology for further classification and ranking of contaminated sites provides a site score based on the merits of the individual site characteristics and not as a comparison with other sites in the database. Application of the methodology to 20 randomly selected sites produced a ranking that was readily verifiable. The first four sites out of twenty were examined in detail and each of the impact factor rankings were verified through the examination of the screened data. Since the final rank is a combination of these factors, the final ranking is validated and the methodology is accepted.

Site #1 and #18 indicate the importance of continual monitoring. A site categorized in one of the lower Classes should be revisited at some point to ensure that the type and quantity of contaminants has not dramatically changed resulting in a shift to a higher classification requiring more attention. This model allows a complete visual comparative of the information, illustrating what and where the changes have occurred and by what magnitude. This enables the decision-makers to determine what action is to be taken and how quickly the response needs to be.



**Table 5-44: Level 3 Classification & Ranking Results**

| Site | Report Date | AENV Generic<br>Property Use | EXCEEDANCE |            |       | Potential<br>Human<br>Impact<br>Factor<br>(PHIF) | Potential<br>Ecological<br>Impact<br>Factor<br>(PEIF) | Potential<br>Political<br>Impact<br>Factor<br>(PPIF) | Preliminary<br>Potential<br>Impact<br>Score<br>(PPIS) | Final<br>Score | Final<br>Rank | Class      |
|------|-------------|------------------------------|------------|------------|-------|--|---|--|---|----------------|---------------|------------|
|      |             |                              | Reported   | Identified |       |  |   |  |   |                |               |            |
|      |             |                              |            | Soil       | Water |  |   |  |   |                |               |            |
| 1    | 05 Jun 1997 | C;C;C;C;RP                   | Both       | Yes        | Yes   | 1.000  | 0.191   | 0.382  | 0.562   | 0.562          | 1             | Class C    |
| 9    | 18 Nov 1997 | C;A;A;RP;A                   | Both       | Yes        | Yes   | 0.932  | 0.292   | 0.146  | 0.512   | 0.512          | 2             | Class C    |
| 22   | 05 Aug 2004 | I;RP;RP;RP;RP                | Both       | Yes        | Yes   | 0.528  | 0.258   | 0.509  | 0.429   | 0.429          | 3             | Class D    |
| 23   | 01 Sep 2005 | RP;RP;RP;RP;C                | Both       | Yes        | Yes   | 0.622  | 0.204   | 0.360  | 0.410   | 0.410          | 4             | Class D    |
| 44   | 01 Feb 2000 | I;I;I;I;RP                   | Both       | Yes        | Yes   | 0.332  | 0.489   | 0.410  | 0.407   | 0.407          | 5             | Class D    |
| 20   | 06 Apr 2005 | C;RP;RP;C;C                  | Soil       | Yes        | Yes   | 0.275  | 0.339   | 0.402  | 0.329   | 0.329          | 6             | Class D    |
| 16   | 30 Apr 2004 | RP;RP;RP;I;RP                | Both       | Yes        | N/A   | 0.500  | 0.172   | 0.240  | 0.320   | 0.320          | 7             | Class D    |
| 13   | 30 Apr 2004 | RP;RP;RP;RP;RP               | Both       | Yes        | Yes   | 0.409  | 0.198   | 0.299  | 0.308   | 0.308          | 8             | Class D    |
| 15   | 30 Apr 2004 | RP;RP;RP;RP;RP               | None       | Yes        | N/A   | 0.387  | 0.199   | 0.320  | 0.304   | 0.304          | 9             | Class D    |
| 17   | 30 Apr 2004 | RP;RP;RP;I;I                 | None       | Yes        | Yes   | 0.435  | 0.145   | 0.240  | 0.284   | 0.284          | 10            | Class D    |
| 27   | 11 Jan 2002 | A;A;A;A;RP                   | Water      | Yes        | Yes   | 0.258  | 0.433   | 0.042  | 0.266   | 0.266          | 11            | Class D    |
| 21   | 24 Jun 1997 | C;C;C;RP;RP                  | Both       | Yes        | Yes   | 0.000  | 0.256   | 0.574  | 0.233   | 0.233          | 12            | Class D    |
| 19   | 06 Apr 2005 | C;C;C;C;C                    | Soil       | Yes        | N/A   | 0.284  | 0.117   | 0.270  | 0.222   | 0.222          | 13            | Class D    |
| 37   | 12 Feb 1997 | C;C;RP;RP;RP                 | Soil       | Yes        | Yes   | 0.000  | 0.249   | 0.455  | 0.201   | 0.201          | 14            | Class D    |
| 6    | 14 Feb 1996 | C;RP;RP;C;RP                 | Both       | Yes        | Yes   | 0.026  | 0.186   | 0.502  | 0.201   | 0.201          | 14            | Class D    |
| 31   | 01 Feb 2006 | C;C;C;C;C                    | Both       | Yes        | Yes   | 0.000  | 0.258   | 0.419  | 0.195   | 0.195          | 15            | Class 2III |
| 10   | 18 Oct 1999 | C;RP;C;RP;RP                 | Soil       | Yes        | N/A   | 0.000  | 0.202   | 0.482  | 0.191   | 0.191          | 16            | Class 2III |
| 11   | 20 Mar 2002 | RP;RP;RP;RP;RP               | Both       | Yes        | Yes   | 0.000  | 0.335   | 0.280  | 0.187   | 0.187          | 17            | Class 2III |
| 18   | 08 Feb 1995 | C;C;C;C;RP                   | BOTH       | Yes        | Yes   | 0.000  | 0.202   | 0.382  | 0.166   | 0.166          | 18            | Class 2III |
| 7    | 01 Dec 2004 | C;C;I;RP;RP                  | Both       | Yes        | Yes   | 0.000  | 0.254   | 0.260  | 0.154   | 0.154          | 19            | Class 2III |

**Table 5-45: Level 3 Classification & Ranking Results – PHIF Score Review (Part 1)**

| Site | Report Date | AENV Generic<br>Property Use | EXCEEDANCE |            |       | Soil Component |                  | Water Component |                  | Total        |                  | Level of Concern |                  | PHIF   |
|------|-------------|------------------------------|------------|------------|-------|----------------|------------------|-----------------|------------------|--------------|------------------|------------------|------------------|--------|
|      |             |                              | Reported   | Identified |       | Carcinogenic   | Non-Carcinogenic | Carcinogenic    | Non-Carcinogenic | Carcinogenic | Non-Carcinogenic | Transformed      |                  |        |
|      |             |                              |            | Soil       | Water |                |                  |                 |                  |              |                  | Carcinogen       | Non-Carcinogenic |        |
| 1    | 05 Jun 1997 | C;C;C;C;RP                   | Both       | Yes        | Yes   | 1.533E-07      | 9.688E-05        | 4.107E-01       | 4.948E+01        | 4.107E-01    | 4.948E+01        | 1.0000           | 1.0000           | 1.0000 |
| 6    | 14 Feb 1996 | C;RP;RP;C;RP                 | Both       | Yes        | Yes   | 2.151E-06      | 1.396E-03        | 0.000E+00       | 0.000E+00        | 2.151E-06    | 1.396E-03        | 0.0512           | 0.0000           | 0.0256 |
| 7    | 01 Dec 2004 | C;C;I;RP;RP                  | Both       | Yes        | Yes   | 5.288E-08      | 3.216E-05        | 0.000E+00       | 0.000E+00        | 5.288E-08    | 3.216E-05        | 0.0000           | 0.0000           | 0.0000 |
| 9    | 18 Nov 1997 | C;A;A;RP;A                   | Both       | Yes        | Yes   | 3.626E-08      | 2.420E-05        | 2.340E-01       | 5.986E+00        | 2.340E-01    | 5.986E+00        | 1.0000           | 0.8648           | 0.9324 |
| 10   | 18 Oct 1999 | C;RP;C;RP;RP                 | Soil       | Yes        | N/A   | 2.632E-07      | 2.135E-04        | 0.000E+00       | 0.000E+00        | 2.632E-07    | 2.135E-04        | 0.0000           | 0.0000           | 0.0000 |
| 11   | 20 Mar 2002 | RP;RP;RP;RP;RP               | Both       | Yes        | Yes   | 0.000E+00      | 5.818E-08        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 5.818E-08        | 0.0000           | 0.0000           | 0.0000 |
| 13   | 30 Apr 2004 | RP;RP;RP;RP;RP               | Both       | Yes        | Yes   | 0.000E+00      | 5.632E+00        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 5.632E+00        | 0.0000           | 0.8176           | 0.4088 |
| 15   | 30 Apr 2004 | RP;RP;RP;RP;RP               | None       | Yes        | N/A   | 0.000E+00      | 5.306E+00        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 5.306E+00        | 0.0000           | 0.7742           | 0.3871 |
| 16   | 30 Apr 2004 | RP;RP;RP;I;RP                | Both       | Yes        | N/A   | 0.000E+00      | 1.759E+01        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 1.759E+01        | 0.0000           | 1.0000           | 0.5000 |
| 17   | 30 Apr 2004 | RP;RP;RP;I;I                 | None       | Yes        | Yes   | 0.000E+00      | 6.020E+00        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 6.020E+00        | 0.0000           | 0.8693           | 0.4347 |
| 18   | 08 Feb 1995 | C;C;C;C;RP                   | Both       | Yes        | Yes   | 2.400E-07      | 1.667E-04        | 0.000E+00       | 0.000E+00        | 2.400E-07    | 1.667E-04        | 0.0000           | 0.0000           | 0.0000 |
| 19   | 06 Apr 2005 | C;C;C;C;C                    | Soil       | Yes        | N/A   | 0.000E+00      | 3.534E+00        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 3.534E+00        | 0.0000           | 0.5689           | 0.2845 |
| 20   | 06 Apr 2005 | C;RP;RP;C;C                  | Soil       | Yes        | Yes   | 0.000E+00      | 3.261E+00        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 3.261E+00        | 0.0000           | 0.5508           | 0.2754 |
| 21   | 24 Jun 1997 | C;C;C;RP;RP                  | Both       | Yes        | Yes   | 1.726E-07      | 1.297E-04        | 0.000E+00       | 0.000E+00        | 1.726E-07    | 1.297E-04        | 0.0000           | 0.0000           | 0.0000 |
| 22   | 05 Aug 2004 | I;RP;RP;RP;RP                | Both       | Yes        | Yes   | 2.251E-06      | 1.035E+01        | 0.000E+00       | 0.000E+00        | 2.251E-06    | 1.035E+01        | 0.0556           | 1.0000           | 0.5278 |
| 23   | 01 Sep 2005 | RP;RP;RP;RP;C                | Both       | Yes        | Yes   | 2.999E-04      | 3.315E+00        | 0.000E+00       | 0.000E+00        | 2.999E-04    | 3.315E+00        | 0.6889           | 0.5544           | 0.6216 |
| 27   | 11 Jan 2002 | A;A;A;A;RP                   | Water      | Yes        | Yes   | 0.000E+00      | 2.753E+00        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 2.753E+00        | 0.0000           | 0.5169           | 0.2584 |
| 31   | 01 Feb 2006 | C;C;C;C;C                    | Both       | Yes        | Yes   | 0.000E+00      | 4.387E-06        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 4.387E-06        | 0.0000           | 0.0000           | 0.0000 |
| 37   | 12 Feb 1997 | C;C;RP;RP;RP                 | Soil       | Yes        | Yes   | 4.027E-07      | 2.808E-04        | 0.000E+00       | 0.000E+00        | 4.027E-07    | 2.808E-04        | 0.0000           | 0.0000           | 0.0000 |
| 44   | 01 Feb 2000 | I;I;I;I;RP                   | Both       | Yes        | Yes   | 0.000E+00      | 4.484E+00        | 0.000E+00       | 0.000E+00        | 0.000E+00    | 4.484E+00        | 0.0000           | 0.6646           | 0.3323 |

**Table 5-46: Level 3 Classification & Ranking Results – PEIF Score Review**

| Site | Estimated Impacted Area  |             | Ecological Persistence (EP <sub>ECOL</sub> ) |        |                    | Ecological Toxicity (ET <sub>ECOL</sub> ) | Biota Bioaccumulation (EB <sub>ECOL</sub> ) |                                   |                    | Estimated Mobility & GW Contamination (MGCP <sub>ECOL</sub> ) |                                       |                         | Surface Water Proximity SWP <sub>ECOL</sub> | Estimated Salinity Effect (SE <sub>ECOL</sub> ) |                     |                    |                    |
|------|--------------------------|-------------|--|--------|--------------------|---|---|-----------------------------------|--------------------|---|---------------------------------------|-------------------------|---|---|---------------------|--------------------|--------------------|
|      | Actual (m <sup>2</sup> ) | Transformed | Soil   | Water  | EP <sub>ECOL</sub> |   | Aquatic (AB <sub>ECOL</sub> )               | Terrestrial (TB <sub>ECOL</sub> ) | EB <sub>ECOL</sub> | Chemical Mobility EM <sub>ECOL</sub>                          | Groundwater Depth GWD <sub>ECOL</sub> | (MGCP <sub>ECOL</sub> ) |   | EC <sub>ECOL</sub>                              | SAR <sub>ECOL</sub> | pH <sub>ECOL</sub> | SE <sub>ECOL</sub> |
| 1    | 2250                     | 0.0414      | 0.1696                                       | 0.1895 | 0.3590             | 0.2015                                    | 0.0322                                      | 0.0485                            | 0.0403             | 0.4903  | 0.5546                                | 0.5225                  | 0.0000                                      |   |                     |                    |                    |
| 6    | 525                      | 0.0065      | 0.0713                                       | 0.0000 | 0.0713             | 0.0313                                    | 0.0000                                      | 0.0449                            | 0.0224             | 0.5567  | 0.8328                                | 0.6947                  | 0.0000                                      |   |                     |                    |                    |
| 7    | 8520                     | 0.1680      | 0.0915                                       | 0.0022 | 0.0937             | 0.0002                                    | 0.0073                                      | 0.0051                            | 0.0062             | 0.1511  | 0.5853                                | 0.3682                  | 0.0000                                      | 0.404   |                     | 1.000              | 0.702              |
| 9    | 3600                     | 0.0686      | 0.0915                                       | 0.6167 | 0.7082             | 0.0712                                    | 0.0478                                      | 0.0682                            | 0.0580             | 0.3069  | 0.5393                                | 0.4231                  | 0.3960                                      |   |                     |                    |                    |
| 10   | 17480                    | 0.3490      | 0.0289                                       | 0.0000 | 0.0289             | 0.0144                                    | 0.0000                                      | 0.0440                            | 0.0220             | 0.4386  | 0.4333                                | 0.4360                  | 0.0000                                      |   |                     |                    |                    |
| 11   | 90000                    | 0.6470      | 0.0000                                       | 0.5926 | 0.5926             | 0.0000                                    | 0.0547                                      | 0.0317                            | 0.0432             | 0.4870  | 0.2600                                | 0.3735                  | 0.1080                                      |   |                     |                    |                    |
| 13   | 7000                     | 0.1373      | 0.0000                                       | 0.0000 | 0.0000             | 0.5232                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.4793                                | 0.2396                  | 0.0680                                      | 0.000   |                     | 0.740              | 0.370              |
| 15   | 9350                     | 0.1848      | 0.0000                                       | 0.0000 | 0.0000             | 0.7671                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.3020                                | 0.1510                  | 0.0520                                      | 0.000   |                     | 0.700              | 0.350              |
| 16   | 11000                    | 0.2181      | 0.0000                                       | 0.0000 | 0.0000             | 0.8297                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.2700                                | 0.1350                  | 0.0320                                      | 0.000   |                     | 0.400              | 0.200              |
| 17   | 5500                     | 0.1070      | 0.0000                                       | 0.0000 | 0.0000             | 0.6993                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.3260                                | 0.1630                  | 0.0200                                      | 0.000   |                     | 0.400              | 0.200              |
| 18   | 2250                     | 0.0414      | 0.0451                                       | 0.1587 | 0.2038             | 0.3816                                    | 0.0809                                      | 0.0795                            | 0.0802             | 0.5639  | 0.5233                                | 0.5436                  | 0.0000                                      |   |                     |                    |                    |
| 19   | 3620                     | 0.0690      | 0.0000                                       | 0.0000 | 0.0000             | 0.5936                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.4000                                | 0.2000                  | 0.0000                                      |   |                     |                    |                    |
| 20   | 2640                     | 0.0492      | 0.0000                                       | 0.0000 | 0.0000             | 0.5318                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.4000                                | 0.2000                  | 0.0000                                      | 1.000   | 1.000               | 1.800              | 1.267              |
| 21   | 3500                     | 0.0666      | 0.0363                                       | 0.8087 | 0.8450             | 0.0509                                    | 0.0281                                      | 0.0629                            | 0.0455             | 0.5458  | 0.7400                                | 0.6429                  | 0.0000                                      |   |                     |                    |                    |
| 22   | 4050                     | 0.0777      | 0.0001                                       | 0.0219 | 0.0220             | 0.5163                                    | 0.0476                                      | 0.0243                            | 0.0360             | 0.0055  | 0.9040                                | 0.4547                  | 0.0680                                      | 0.000   |                     | 1.000              | 0.500              |
| 23   | 8050                     | 0.1585      | 0.0000                                       | 0.0000 | 0.0000             | 0.1821                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.4666                                | 0.2333                  | 0.0680                                      | 0.000   |                     | 1.000              | 0.500              |
| 27   | 146000                   | 0.9106      | 0.0000                                       | 0.0000 | 0.0000             | 0.6822                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 1.0000                                | 0.5000                  | 0.0960                                      |   |                     |                    |                    |
| 31   | 6210                     | 0.1214      | 0.0000                                       | 0.0000 | 0.0000             | 0.8812                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.5453                                | 0.2726                  | 0.0000                                      | 1.000   |                     | 0.200              | 0.600              |
| 37   | 6888                     | 0.1351      | 0.0348                                       | 0.3632 | 0.3980             | 0.3833                                    | 0.0598                                      | 0.0776                            | 0.0687             | 0.5476  | 0.6064                                | 0.5770                  | 0.0000                                      |   |                     |                    |                    |
| 44   | 302175                   | 1.0000      | 0.0000                                       | 0.0000 | 0.0000             | 0.5815                                    | 0.0000                                      | 0.0000                            | 0.0000             | 0.0000  | 0.4400                                | 0.2200                  | 0.0320                                      | 1.000   |                     | 1.000              | 1.000              |

**Table 5-47: Level 3 Classification & Ranking Results – PPIF Score Review**

| Site | Report Date | AENV Generic Property Use | EXCEEDANCE |            |       | Onsite Activity Factor (OAF <sub>ECOL</sub> ) |                                      |  |                     | Land and Property Use Factor (LPF <sub>ECOL</sub> ) |       |                     |
|------|-------------|---------------------------|------------|------------|-------|---|--------------------------------------|--|---------------------|---|-------|---------------------|
|      |             |                           | Reported   | Identified |       | Tank Component (TC <sub>ECOL</sub> )          | PCA Component (PCA <sub>ECOL</sub> ) | Foreign Utility Service Component (FUS <sub>ECOL</sub> ) | OAF <sub>ECOL</sub> | LUSF  | ΣLURF | LPF <sub>ECOL</sub> |
|      |             |                           |            | Soil       | Water |   |                                      |  |                     |   |       |                     |
| 1    | 05 Jun 1997 | C;C;C;C;RP                | Both       | Yes        | Yes   | 0.750   | 1.000                                | 0.000  | 0.243               | 0.800   | 1.800 | 0.520               |
| 6    | 14 Feb 1996 | C;RP;RP;C;RP              | Both       | Yes        | Yes   | 0.750   | 1.000                                | 0.000  | 0.243               | 1.000   | 2.800 | 0.760               |
| 7    | 01 Dec 2004 | C;C;I;RP;RP               | Both       | Yes        | Yes   | 0.000   | 0.000                                | 0.000  | 0.000               | 0.800   | 1.800 | 0.520               |
| 9    | 18 Nov 1997 | C;A;A;RP;A                | Both       | Yes        | Yes   | 1.100   | 1.000                                | 0.000  | 0.292               | 0.000   | 0.000 | 0.000               |
| 10   | 18 Oct 1999 | C;RP;C;RP;RP              | Soil       | Yes        | N/A   | 0.750   | 1.000                                | 0.000  | 0.243               | 1.000   | 2.600 | 0.720               |
| 11   | 20 Mar 2002 | RP;RP;RP;RP;RP            | Both       | Yes        | Yes   | 0.000   | 0.000                                | 0.000  | 0.000               | 0.500   | 2.300 | 0.560               |
| 13   | 30 Apr 2004 | RP;RP;RP;RP;RP            | Both       | Yes        | Yes   | 0.000   | 1.000                                | 0.000  | 0.139               | 0.400   | 1.900 | 0.460               |
| 15   | 30 Apr 2004 | RP;RP;RP;RP;RP            | None       | Yes        | N/A   | 0.000   | 0.000                                | 0.000  | 0.000               | 0.500   | 2.700 | 0.640               |
| 16   | 30 Apr 2004 | RP;RP;RP;I;RP             | Both       | Yes        | N/A   | 0.000   | 0.000                                | 0.000  | 0.000               | 0.500   | 1.900 | 0.480               |
| 17   | 30 Apr 2004 | RP;RP;RP;I;I              | None       | Yes        | Yes   | 0.000   | 0.000                                | 0.000  | 0.000               | 0.500   | 1.900 | 0.480               |
| 18   | 08 Feb 1995 | C;C;C;C;RP                | Both       | Yes        | Yes   | 0.750   | 1.000                                | 0.000  | 0.243               | 0.800   | 1.800 | 0.520               |
| 19   | 06 Apr 2005 | C;C;C;C;C                 | Soil       | Yes        | N/A   | 0.000   | 0.000                                | 0.000  | 0.000               | 1.000   | 1.700 | 0.540               |
| 20   | 06 Apr 2005 | C;RP;RP;C;C               | Soil       | Yes        | Yes   | 0.000   | 0.600                                | 0.000  | 0.083               | 1.000   | 2.600 | 0.720               |
| 21   | 24 Jun 1997 | C;C;C;RP;RP               | Both       | Yes        | Yes   | 0.800   | 3.000                                | 0.000  | 0.528               | 1.000   | 2.100 | 0.620               |
| 22   | 05 Aug 2004 | I;RP;RP;RP;RP             | Both       | Yes        | Yes   | 1.800   | 2.800                                | 0.000  | 0.639               | 0.700   | 1.200 | 0.380               |
| 23   | 01 Sep 2005 | RP;RP;RP;RP;C             | Both       | Yes        | Yes   | 0.525   | 1.200                                | 0.000  | 0.240               | 0.400   | 2.000 | 0.480               |
| 27   | 11 Jan 2002 | A;A;A;A;RP                | Water      | Yes        | Yes   | 0.000   | 0.600                                | 0.000  | 0.083               | 0.000   | 0.000 | 0.000               |
| 31   | 01 Feb 2006 | C;C;C;C;C                 | Both       | Yes        | Yes   | 0.000   | 2.000                                | 0.000  | 0.278               | 1.000   | 1.800 | 0.560               |
| 37   | 12 Feb 1997 | C;C;RP;RP;RP              | Soil       | Yes        | Yes   | 0.650   | 1.000                                | 0.000  | 0.229               | 0.800   | 2.600 | 0.680               |
| 44   | 01 Feb 2000 | I;I;I;I;RP                | Both       | Yes        | Yes   | 0.850   | 2.600                                | 0.000  | 0.479               | 0.800   | 0.900 | 0.340               |

## CHAPTER SIX: A COMPARATIVE APPROACH FOR RANKING CONTAMINATED SITES BASED ON THE RISK ASSESSMENT PARADIGM USING *FUZZY* PROMETHEE<sup>4</sup>

### 6.1 GENERAL

When evaluating hazardous sites, there is a significant amount of site-specific parameters that need to be combined and assessed. Often the data available is highly variable, incomplete, linguistic in nature, vague and uncertain and fuzzy logic allows for quantitative representation of the data available. Multi-objective decision making becomes important when more than one objective constrains a problem and each of the objectives has a different weight associated with them. The typical MODM problem involves the selection of one alternative from a group of alternatives given a collection of criteria or objectives. (Ross 2004) Each alternative must be evaluated on how well it satisfies the objective and how much it contributes to the overall decision.

In the case of ranking of contaminated sites, each site represents an alternative that is evaluated based on a number of criteria and the importance of the criteria with respect to some overall objective. One multicriteria method that can be applied is an outranking method known as PROMETHEE, or Preference Ranking Organization Method for Enrichment Evaluation. The method uses binary relations on a set of potential actions to develop a preference relation between and within alternatives (Bouyssou 2005; Wang and Triantophyllou 2006). A complete ranking can be obtained through the use of PROMETHEE II to ensure that all alternatives are comparable (Brans and Mareschal 2005). The data available is used in its original form (i.e. not manipulated) and makes the application relatively easy and transparent. In order to adequately address uncertainty in information, the method is extended to include the concepts of fuzzy sets. By combining CRA methodology and the risk assessment paradigm, a comparative approach for ranking of contaminated is presented.

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<sup>4</sup>This chapter is a modified version of the published peer reviewed paper by Zhang, K., Kluck, C., and Achari, G. (2009). "A Comparative Approach for Ranking Contaminated Sites Based on the Risk Assessment Paradigm Using Fuzzy PROMETHEE." *Environmental Management*, 44(5), 952-967.

## 6.2 CRITERIA IDENTIFICATION

The criteria identified for use in the PROMETHEE method should be:

1. based on information that is relevant, easily obtainable, and clearly understood by both the decision makers and the analysts (Brans and Mareschal 2005),
2. contributing factors in the decision making process but they do not need to be mathematically linked
3. self-contained and be expressed in their own units, thereby reducing any scaling effects that could affect the outcome.

Each of the criteria identified are assigned preference weights at the discretion of the decision makers and generally reflect the relative importance of each criteria in the decision making process. For the purposes of ranking sites, all criteria identified are considered to be of equal importance, and thus of equal weighting.

In order to identify the criteria to be utilized, all site characteristics that impact the site rank were identified and are listed in Table 6-1.

**Table 6-1 Site Characteristics Impacting Rank**

|  |                        |                                     |
|--|------------------------|-------------------------------------|
| Contaminant Characteristics                        | Concentration          | soil                                |
|  |                        | water                               |
|  | Toxicity               | Carcinogenic and weight of evidence |
|  |                        | Non-carcinogenic                    |
|  | Chemical properties    | Volatilization                      |
|  |                        | Persistence                         |
| Bioavailability                                    |                        |                                     |
| Volume of contaminated soil                        |                        |                                     |
| Volume of contaminated surface and /or groundwater |                        |                                     |
| Groundcover Type                                   | permeable              |                                     |
|  | Impermeable            |                                     |
|  | Mixed                  |                                     |
| Potential Receptor                                 | Adult                  |                                     |
|  | Child                  |                                     |
|  | Adult worker           |                                     |
| Exposure   | Duration               |                                     |
|  | Frequency              |                                     |
| Soil characteristics                               | Hydraulic conductivity |                                     |
|  | Porosity               |                                     |
|  | Hydraulic gradient     |                                     |

Conversion of these characteristics into criteria is performed based on the type of characteristic, the relationship of the information available and how the information can be combined. For the process of ranking sites based on the human health and ecological risk assessment paradigms, twelve criteria have been identified as significant contributing factors to the assessment process.

Examination of the contaminant characteristics that can impact rank reveals that concentration and toxicity has a direct impact on health risk and should be combined into one criteria. However, further separation is required to account for carcinogenicity or non-carcinogenicity resulting in two essential criteria:

**Criteria 1: Soil Carcinogenic Risk Index (SCRI)**

This criterion accounts for the total carcinogenic impact of the contaminants present at the site as well as their carcinogenic weight-of-evidence. Carcinogenic impact is related to the amount of chemical present at the site (mg/kg soil) and the critical dosage for adverse effects (slope factor,  $(\text{mg/kg-day})^{-1}$ ). As each carcinogen identified through laboratory experiments or epidemiological studies has a “Weight -of-Evidence” classification attributed to it, in order to use this linguistic information weights (Carcinogenic Class Impact, CCI) have been assigned to each classification to represent the degree of impact a compound with that classification would have on the overall health risk assessment; the higher the weight, the higher the impact. Depending on the country of origin, the carcinogenic classification/ranking scheme varies (Table 2-1). The original USEPA carcinogen classification has been selected for the purpose of this criterion as the majority of contaminants have not been reclassified under the new, linguistic system (Muller 2002). The classifications, descriptions and associated weights are presented in Table 6-2.

**Table 6-2 Weight-of-Evidence Classification and Associated Impact Values**

| Weight of Evidence |   | CCI |
|--------------------|---|-----|
| Class A            | known human carcinogen  | 1.0 |
| Class B1           | Probable human carcinogen with limited evidence in humans   | 0.8 |
| Class B2           | Probable human carcinogen with sufficient evidence in animals but inadequate or no evidence in humans | 0.6 |
| Class C            | Possible human carcinogen   | 0.4 |
| Class D            | Not classified as human carcinogen  | 0.2 |
| Class E            | Evidence of non-carcinogenicity in humans   | 0.0 |
|                    | Not identified as carcinogen in humans or animals   | 0.0 |

As many contaminants may be present at any given site in any combination, risks are typically estimated by assuming that the individual contributions are additive (Health Canada 2004a; Paustenbach 2002; USEPA 1989). Following this recommended methodology, the overall Soil Carcinogenic Risk Index (SCRI) is evaluated as follows:

**Equation 6-1: Soil Carcinogenic Risk Index (SCRI)**

$$SCRI = \sum_{i=1}^n C_{S,i} \times SF_i \times CCI_i$$

where

$C_{S,i}$  =  $i$ th chemical concentration in soil

$SF$  = slope factor

**Criteria 2: Soil Non-Carcinogenic Risk Index (SNCRI)**

This criterion accounts for the total non-carcinogenic impact of all the chemicals identified within the site. Those chemicals classified as carcinogens are included in the assessment as exposure to these compounds may also result in non-carcinogenic adverse



health effects (e.g. respiratory illness, organ damage). Non-carcinogenic impact reflects the magnitude of the adverse effects and is proportional to the chemical concentrations available (mg/kg) and the critical dosage that is known to result in adverse effects (reference dose, RfD, mg/kg-day). For multiple chemical exposures the individual contributions are considered to be additive, as in the NCRI:

**Equation 6-2: Non-Carcinogenic Risk Index (SNCRI)**

$$SNCRI = \sum_{i=1}^n \frac{C_{Si}}{RfD_i}$$

where,

$C_{Si}$  =  $i$ th chemical concentration in soil

$RfD_i$  = Chemical specific reference dose

The remaining characteristics identified in Table 6-1 are independent of dosage and thereby transformed into separate criteria as follows:

**Criteria 3: Partition Index (PI)**

Contaminant transport through media is dependent upon how the chemical of concern (COC) reacts in the presence of water (hydrophobic/hydrophilic) and the properties of the media itself (i.e. soil moisture, soil organic content, soil texture, pH). Partition coefficients are generally used to describe the distribution of chemicals between two phases (solid-vapor, solid-liquid, liquid-vapor, two immiscible liquids, two solids, etc) and the environmental fate of organic compounds (LaGrega et al. 2001). In order to account for the concentration of the contaminants detected in water samples the soil-water partition coefficient,  $K_d$ , is selected. This coefficient describes the tendency of an organic chemical to preferentially bind to soil or sediment rather than remaining in pore water or groundwater. The higher the  $K_d$  value, the greater the tendency of the chemical to bind to the soil and hence, the lower its mobility and potential for groundwater infiltration. The degree of sorption is dependent on the specific chemical's

characteristics and, when multiple chemicals are involved each will sorb differently in the same media. To account for this variation a site specific  $K_d$  value for each chemical is evaluated and proportioned by the fraction of each chemical contributing to the potential hazard ranking of the site ( $F_{s,i}$ ).

**Equation 6–3: Soil-Water Partition Coefficient**

$$K_{d,i} = \frac{COC_{Soil}}{COC_{Water}}$$

where

$$\begin{aligned} COC_{Soil} &= \text{Contaminant of Concern concentration in soil} \\ COC_{Water} &= \text{Contaminant of Concern concentration in water} \end{aligned}$$

**Equation 6–4: Chemical Fraction ( $F_{s,i}$ )**

$$F_{s,i} = \frac{C_{coc}}{C_T}$$

where

$$\begin{aligned} C_{coc} &= \text{Concentration of contaminant of concern (mg/kg)} \\ C_T &= \text{Total contaminant concentration on site (mg/kg)} \end{aligned}$$

The individual contributions are then considered to be additive in the derivation of the Partition Index (PI):

**Equation 6–5: Partition Index (PI)**

$$PI = \sum_{i=1}^n Fraction_{Soil,i} \times K_{d,i}$$

where

$$\begin{aligned} F_{s,i} &= \text{Chemical fraction (unitless)} \\ K_{d,i} &= \text{Chemical Specific soil-water partition coefficient} \end{aligned}$$

**Criteria 4 & 5: Volume of Contaminated Soil (VCS) and Volume of Contaminated Groundwater (VCW)**

Hazard ranking of a site is contingent on the extent of vertical and horizontal contamination. Contaminant spread is based on the amount of chemicals released into the environment, their mode of release and, the specific properties of the contaminants of concern. Volume estimates can be obtained either directly from results of the sampling protocol utilized for each site or, derived from the following equations:

**Equation 6–6: Contaminated Soil Volume (VCS)**

$$VCS = SA \times DDC$$

where,

SA = Surface Area

DDC = Deepest detected contamination

The surface area is estimated from the maximum length and width distances between surface samples and the deepest detected contamination. The deepest detected contamination is selected for this criterion and may extend below the groundwater table. This will account for the sorptive tendency of the contaminants of concern to soils at all depths.

**Equation 6–7: Contaminated Water Volume (VCW)**

$$VCS = SA \times GWD$$

where,

SA = Surface Area

GWD = Depth of contaminated groundwater.

The surface area is represented by plume size or surface sampling distances (as above) and the depth of contaminated groundwater represents the distance between the depth to groundwater and deepest detected contamination within groundwater.

**Criteria 6: Percentage of Permeable Groundcover**

The amount of permeable groundcover will effectively control the level of exposure of a receptor to a contaminant. When dealing with properties located within municipalities, the presence of non-permeable surface capping (e.g. asphalt, concrete, buildings) will restrict exposure to contaminated soil. The amount of surface capping allowed, and hence the portion available for landscaping is generally dictated by the property/land use designations (zoning bylaws) of the municipality (see Table 5-6 to Table 5-13). For example, residential zoned areas typically have greater permeable groundcover than commercially zoned areas and industrial zoned areas may vary (typically asphalt or gravel depending on the business activity). The percentage allocated will be at the discretion of the decision maker or may be dictated by municipal bylaws.

**Criteria 7: Exposure Index (EI)**

Under traditional risk assessment methods, the type of receptor is the main factor in assessing exposure. The most sensitive receptor is identified for the site under consideration. If a site is zoned residential, parkland, agricultural or commercial, both adults and children are exposed to the conditions at that site. However, children are considered to be the most sensitive receptor. If the site under consideration is zoned industrial, exposure is restricted to the adult workers present on the site and thus adults are identified as the most sensitive receptor. Once the zoning and most sensitive receptor are identified, the associated pre-established and statistically determined exposure factors (Table 5-15) are used to evaluate the Exposure Index (EI) criterion:

**Equation 6-8: Exposure Index (EI)**

$$EI = \frac{ED \times EF}{BW}$$

where,

ED = Exposure duration

EF = Exposure frequency

BW = Receptor body weight

### **Criteria 8: Vapor Pressure Index (VPI)**

Volatilization of chemicals has a direct impact on inhalation and dermal absorption exposure pathways. Therefore, the greater the number of volatile compounds present, the greater the impact. The tendency of a chemical to move from solid or liquid to a vapour state is given by its specific equilibrium vapour pressure and since vapour pressure is temperature dependent, the actual volatilization rate will depend on the environmental conditions at the site. In the absence of site- specific volatilization rates, all contaminants are assumed to be exposed to the same conditions and thus standardized vapour pressures (@ 20-25°C) are used. In order to account for the presence of multiple chemicals in a vapour state a Vapour Pressure Index (VPI) is proposed. The index considers the contribution of each contaminant of concern as additive and therefore proportions the contribution of each to the final value by combining the mass fraction with the associated vapour pressure.

#### **Equation 6–9: Vapour Pressure Index (VPI)**

$$VPI = \sum_{i=1}^n VP_i \times F_{Si}$$

where,

$VP_i$  = Chemical specific Vapour pressure

$F_{Si}$  = Chemical fraction (see Equation 6–4)

**Criteria 9: Total Groundwater Ubiquity Score (GUS)**

Chemical persistence in soil and groundwater media is reflective of the chemicals resistance to degradation mechanisms and sorptive properties. The more resistive to degradation the longer the chemical persists in its original form and when coupled with a low sorption affinity, the greater the potential for leaching into groundwater. The importance of adsorption and persistence for chemicals in soils has been illustrated by Gustafson (1993) through the use of the Groundwater Ubiquity Score (GUS) index (Gustafson 1993). The GUS is calculated as follows:

**Equation 6–10: Groundwater Ubiquity Score (GUS)**

$$GUS = \log(t_{1/2}) \times (4 - \log K_{oc})$$

where,

$t_{1/2}$  = Dissipation half-life of the chemical (days)

$K_{oc}$  = Organic carbon partition coefficient

The effects of different chemicals are assumed to be additive and thus the total GUS (TGUS) is given by:

**Equation 6–11: Total GUS (TGUS)**

$$TGUS = \sum_{i=1}^n GUS_i$$

**Criteria 10: Hydraulic Conductivity**

Hydraulic conductivity is a measure of the ability of fractured or porous media to transmit water (Fetter 1999) and thus is one of several contributing factors that influence the contaminant fate and transport process. In the absence of site specific measurements, standardized values may be applied for typical soil types (sand, gravel, silt, clay, etc).

### Criteria 11: Ecological Toxicity Index (ETI)

In evaluating the ecological impact of contaminants in soil an indicator species associated with the site is typically selected for toxicity analysis. The most frequently selected indicator species is the earthworm *Eisenia fetida* (Weeks 1998) The selection is based on (1) their high rate of exposure to organics and inorganics via feeding and burrowing activities and (2) contribution to diets of animals higher in the food chain. (Efroymson et al. 1997). The effects of 90 chemicals on *Eisenia fetida* were examined and five categories of ecological toxicity were identified (Roberts and Dorrough 1983):

1. super toxic:  $LC_{50} < 1.0 \mu\text{g}/\text{cm}^2$
2. extremely toxic:  $1 \mu\text{g}/\text{cm}^2 < LC_{50} < 10 \mu\text{g}/\text{cm}^2$
3. very toxic:  $10 \mu\text{g}/\text{cm}^2 < LC_{50} < 100 \mu\text{g}/\text{cm}^2$
4. moderate toxic:  $100 \mu\text{g}/\text{cm}^2 < LC_{50} < 1000 \mu\text{g}/\text{cm}^2$
5. relatively non-toxic:  $1000 \mu\text{g}/\text{cm}^2 < LC_{50}$

To adequately represent the toxicity level associated with multiple contaminants, an Ecological Toxicity Index (ETI) is proposed assuming additivity of fractions:

#### Equation 6–12: Ecological Toxicity Index (ETI)

$$ETI = \sum_{i=1}^n LC_{50}$$

### Criteria 12: Bioconcentration Index (BCI)

There are several terms which describe the accumulation of organic and/or inorganic chemicals within living biota. The difference relates to the process by which this occurs: bioaccumulation occurs through exposure to contaminated media, directly (oral, dermal, inhalation pathways) or indirectly (consumption of food containing the chemical); bioconcentration occurs when the contaminant levels within the organism have increased to levels above the surrounding environment; biomagnification involves increased exposure through the food chain. Food chain effects serve as important indicators of

ecological stress. The common method of evaluating ecological effects is through the comparative assessment of contaminant concentration in living organisms and in the subject sites water and/or soil.

Several transport models have been developed to account for plant-to-soil and plant-to-air bioaccumulation but their reliability is reportedly limited (McKone and Maddalena 2007). The majority of the models attempt to correlate uptake with the octanol-water partition coefficient,  $K_{ow}$ . However, the results vary with some models indicating a positive correlation and others a negative correlation (Suter et al. 2007). The model selected to depict soil-to-plant contaminant transfer is given by (Travis and Arms 1988):

**Equation 6–13: Bioconcentration Factor (Soil-to-Plant)**

$$\text{Log}(BCF) = 1.588 - 0.578\text{Log}(Kow)$$

This model indicates that contaminant uptake by plants is *inversely* proportional to the square-root of the octanol-water partition coefficient ( $K_{ow}$ ) as transport from the roots to the upper portion of the plant is dependent upon the tendency of the contaminant to partition into water. Translocation and bioconcentration into plant tissue follows root uptake and is dependent on the water and lipid content in the plant tissues; plant lipids are classified as triglycerides, membrane lipids (e.g. fatty acids) or cuticular lipids (Dey and Harborne 1997). This empirical model is considered valid for compounds with log  $Kow$  values between 1 and 9 (McKone and Maddalena 2007), and is selected here.

As the contaminants are located in soil and/or groundwater, the most suitable organism for the assessment of bioconcentration is the earthworm (refer to Criteria 11). Several models have been proposed with for various organisms and the one selected is a bioconcentration model for earthworms based on organic compounds with log  $Kow$  values between 1 and 6.5. (Connel and Markwell 1990)

**Equation 6–14: Bioconcentration Factor (Soil-to-Earthworm)**

$$\text{Log}(BCF) = \log(Kow) - 0.6$$



As bioconcentration in biota occur concurrently, the Bioconcentration Index will be a combination of the two models and additivity of multiple contaminants is assumed.

**Equation 6–15: Bioconcentration Index (BCI)**

$$BCI = \sum_{i=1}^n (\log BCF_{\text{PLANT}} + \log BCF_{\text{EARTHWORM}})$$

### 6.3 PROMETHEE AND FUZZY PROMETHEE

The *Preference Ranking Organization METHod for Enrichment Evaluation* (PROMETHEE) is a subgroup of Multi-Criteria Decision Making Methods developed in the early 1980's by Brans et al. 1984 and Brans and Vincke 1985 . By 1994 PROMETHEE had been extended to encompass six ranking formats: PROMETHEE I (partial ranking), PROMETHEE II (complete ranking), PROMETHEE III (ranking based on intervals), PROMETHEE IV (continuous case), PROMETHEE V(MCDA including segmentation constraints) and PROMETHEE VI (representation of the human brain). The success of this methodology in various industry applications is attributed to its flexibility and ease of use.(Brans and Mareschal 2005)

PROMETHEE methods promulgated by Brans and Mareschal 1986 are based on a set of alternatives,  $A = \{a_1, a_2, \dots, a_n\}$  which will be ordered and a set of criteria,  $F = \{f_1, f_2, \dots, f_m\}$  which must be optimized. A pair wise comparison between two alternatives,  $a_i$  and  $a_j$  is made and the intensity of preference of an action  $a_i$  over action  $a_j$  ( $P_k(d_k)$ ,  $d_k = f_k(a_i) - f_k(a_j)$ ) is determined where  $P_k$  is the preference function for the  $k$ th criterion and  $f_k(a_i)$  is the evaluation of alternative  $a_i$  corresponding to criterion  $f_k$ . They identified/defined six different types of preference functions with preference scale values ranging between 0 (no preference) and 1 (strong preference)(Brans and Mareschal 1986). The preference of action  $a_i$  over  $a_j$  is evaluated for each criterion and the preference function relation  $\pi$  is determined by:

**Equation 6–16: Preference Function,  $\pi$** 

$$\pi(a_i, a_j) = \sum_{k=1}^m w_k p_k(f_k(a_i) - f_k(a_j)), \forall a_i \in A$$

where,

$$\begin{aligned} m &= \text{Total number of criteria} \\ w_k \in A &= \{w_1, w_2, \dots, w_k\} \\ &= \text{criterion weight} \end{aligned}$$

Leaving ( $\Phi^-$ ) and entering ( $\Phi^+$ ) flows of  $a_i$  provide a measure of the alternative being examined with respect to the other alternatives; leaving flow represents the preference of a specific alternative over all the other alternatives and the entering flow is the other alternatives over the specific alternative (i.e. the opposite). These flows are evaluated as follows:

**Equation 6–17: Leaving Flow,  $\Phi^+$** 

$$\Phi^+(a_i) = \frac{1}{n-1} \sum_{\substack{j=1 \\ j \neq i}}^n \pi(a_i, a_j)$$

**Equation 6–18: Entering Flow,  $\Phi^-$** 

$$\Phi^-(a_i) = \frac{1}{n-1} \sum_{\substack{j=1 \\ j \neq i}}^n \pi(a_j, a_i)$$

where,

$$n = \text{Total number of alternatives}$$

The basic principle associated with the entering and leaving flows is that the higher the leaving flow and the lower the entering flow the better the alternative. The PROMETHEE I method leads to a partial pre-order through the comparison of the

leaving flow and entering flows (Brans and Mareschal 2005). For any two alternatives ( $a_i, a_j \in A$ ), one of three relations are possible:

1. Preference ( $P^I$ ): when  $\phi^+(a_i) \geq \phi^+(a_j)$  and  $\phi^-(a_i) \leq \phi^-(a_j)$
2. Indifference ( $I^I$ ):  $\phi^+(a_i) = \phi^+(a_j)$  and  $\phi^-(a_i) = \phi^-(a_j)$
3. Incomparable ( $R^I$ ):  $\phi^+(a_i) > \phi^+(a_j)$  and  $\phi^-(a_i) > \phi^-(a_j)$ , or  
 $\phi^+(a_i) < \phi^+(a_j)$  and  $\phi^-(a_i) < \phi^-(a_j)$ .

PROMETHEE II, however, provides a complete pre-order wherein the total ranking is obtained based on the evaluation of the net flow,  $\Phi^{\text{net}}$ . The net flow is obtained by subtracting the entering flow from the leaving flow,

**Equation 6–19: Net Flow,  $\Phi^{\text{net}}$**

$$\Phi^{\text{net}}(a_i) = \Phi^+(a_i) - \Phi^-(a_i), \forall a_i \in A$$

The higher the net flow the better the alternative. Brans and Mareschal 1986 provide an example of the application of the PROMETHEE methods.

For situations when the input information has non random uncertainty, the PROMETHEE method was extended to (1) consider fuzzy inputs along with crisp weights (Goumas and Lygerou 2000) and (2) use fuzzy preference and fuzzy weights to obtain fuzzy scores (Geldermann et al. 2000). In both cases, trapezoidal fuzzy numbers were selected to represent the uncertainties. The advantage in using a trapezoidal fuzzy number is that a specific value, an interval, and a triangular fuzzy number can all be represented by a specific trapezoidal fuzzy number. The fuzzy PROMETHEE algorithm proposed by Geldermann et al. 2000 is briefly described below:

**Step 1:** Define for each criterion  $f_k$ , a suitable preference function  $p_k(d_k)$ .

**Step 2:** Define a vector containing the fuzzy weights, each in the form of trapezoidal fuzzy numbers:

**Equation 6–20: Fuzzy Weight Vector,  $\tilde{W}^T$**

$$\tilde{W}^T = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_m) \text{ with } \tilde{w}_k = (m_l^w, m_u^w, \alpha^w, \beta^w)_{LR}$$

**Step 3:** Evaluate for all the alternatives  $a_i, a_j \in A$  the fuzzy preference relation  $\tilde{\pi}$ :

**Equation 6–21: Fuzzy Preference,  $\tilde{\pi}(a_i, a_j)$**

$$\tilde{\pi}(a_i, a_j) = \sum_{k=1}^m \tilde{w}_k \langle \times \rangle p_k(f_k(a_i) \langle - \rangle f_k(a_j))$$

where,

$$\begin{aligned} f_k(a_i) &= (m_l, m_u, \alpha, \beta)_{LR} \\ f_k(a_j) &= (n_l, n_u, \gamma, \delta)_{LR} \end{aligned}$$

and, the degree of preference for the comparison of alternatives  $a_i$  and  $a_j$  with regard to criterion  $f_k$  was calculated using fuzzy arithmetic.

**Equation 6–22: Fuzzy Degree of Preference,  $p_k$**

$$p_k(f_k(a_i) \langle - \rangle f_k(a_j)) = (m_l^{p_k}, m_u^{p_k}, \alpha^{p_k}, \beta^{p_k})_{LR}$$

where,

$$\begin{aligned} m_l^{p_k} &= p_k(m_l - n_u) \\ m_u^{p_k} &= p_k(m_u - n_l) \\ \alpha^{p_k} &= p_k(m_l - n_u) - p_k(m_l - n_u - \alpha - \delta) \\ \beta^{p_k} &= p_k(m_l - n_u + \beta + \gamma) - p_k(m_u - n_l) \end{aligned}$$

The fuzzy outranking relation  $\pi$  is determined by:

**Equation 6–23: Fuzzy Outranking,  $\pi(a_i, a_j)$**

$$\pi(a_i, a_j) = (m_l^\pi, m_u^\pi, \alpha^\pi, \beta^\pi)_{LR}$$

where,

$$\begin{aligned} m_l^\pi &= \sum_{k=1}^m (m_l^{w_k} \cdot m_l^{p_k}) \\ m_u^\pi &= \sum_{k=1}^m (m_u^{w_k} \cdot m_u^{p_k}) \\ \alpha^\pi &= \sum_{k=1}^m (m_l^{w_k} \alpha^{p_k} + m_l^{p_k} \alpha^{w_k} - \alpha^{w_k} \alpha^{p_k}) \\ \beta^\pi &= \sum_{k=1}^m (m_u^{w_k} \beta^{p_k} + m_u^{p_k} \beta^{w_k} + \beta^{w_k} \beta^{p_k}) \end{aligned}$$

**Step 4:** Accordingly, for each alternative,  $a_i$ , the fuzzy leaving flow of  $a_i$  is calculated as:

**Equation 6–24: Fuzzy Leaving Flow,  $\phi^+$**

$$\phi^+(a_i) = \frac{1}{n-1} \sum_{\substack{j=1 \\ j \neq i}}^n \pi(a_i, a_j)$$

**Step 5:** As a measure of the weakness of the alternatives,  $a_i \in A$ , the fuzzy entering flow of  $a_i$  is determined by:

**Equation 6–25: Fuzzy Entering Flow,  $\phi^-$**

$$\phi^-(a_i) = \frac{1}{n-1} \sum_{\substack{j=1 \\ j \neq i}}^n \pi(a_j, a_i)$$

**Step 6:** For PROMETHEE I, the fuzzy scores,  $\phi^+(a_i)$  and  $\phi^-(a_i)$  are defuzzified and compared. For PROMETHEE II, the fuzzy scores are aggregated, defuzzified and then compared/ranked.

### 6.3.1 Criteria optimization

Criteria optimization is an essential step in that it provides a means of identifying the impact of a given criterion on the overall risk assessment. A criterion is either maximized or minimized based on the action of a specified attribute and should be established prior to implementing the PROMETHEE or *Fuzzy* PROMETHEE methods. If a higher value for an attribute represents a higher potential for environmental risk, the criterion provided with that attribute should be maximized. Similarly, if a higher attribute value is indicative of a lower/smaller potential for environmental risk, the criterion for this attribute should be minimized and the formula for calculating the difference between alternatives  $a_i$  and  $a_j$  is defined as:

#### Equation 6–26: Alternative Difference (Minimization)

$$d_k = f_k(a_j) - f_k(a_i) > 0$$

### 6.3.2 Criteria preference function selection

Six general types of preference functions have been identified for use in the PROMETHEE method (Brans and Mareschal 1986) with each case requiring the assignment of a select number of specific parameters to reflect the significance of the preference by the decision makers (i.e. indifference, strict preference, intermediate preference). While the general types are considered to be sufficient for most applications, the decision makers may also model their preferences using any other specifically shaped preference functions (Brans and Vincke 1985). The Type III linear preference function is selected here as appropriate for ranking purposes. It is defined by

**Equation 6–27: Type III Linear Preference Function**

$$P_k = \begin{cases} \frac{d_k}{p_k} & \text{if } 0 \leq d_k \leq p_k \\ 1 & \text{if } d_k > p_k \end{cases}$$

where  $d_k = f_k(a_i) - f_k(a_j)$ . The intensity of preference,  $P_k$ , increases linearly with the growth of  $d_k$  up to  $p_k$ . After the threshold,  $p_k$ , has been reached the intensity will be equal to 1. The threshold should be identified by the decision maker and once determined, the preference becomes strict. For ranking purpose the parameter  $p_k$  can be set as:

**Equation 6–28: Threshold parameter,  $p_k$** 

$$p_k = f_k(\cdot)_{\max} - f_k(\cdot)_{\min}$$

where  $f_k(\cdot)$  is the evaluation of all alternatives for criterion  $k$ .

**6.3.3 The Process of Fuzzy PROMETHEE**

The fuzzy PROMETHEE algorithm, steps 1 to step 5 above, are performed for each contaminated site. Evaluation of the leaving flow and entering flow for each contaminated site is similar to the addition of risks for multiple pathways suggested by various regulatory bodies (Health Canada 2004a; USEPA 1989). Step 6 is based on the defuzzification of the total fuzzy leaving flow and entering flow. The Centre of Area (COA) method is selected for the defuzzification as it provides consistent evaluation of both trapezoidal fuzzy data and crisp data (Geldermann et al. 2000).

**6.4 CASE STUDY**

Promethee and Fuzzy Promethee methodology are each applied to four contaminated dry cleaning sites for the purpose of hazard ranking. The data for these sites were obtained from profiles available through the USEPA State Coalition for Remediation of Dry Cleaning Sites (USEPA 2004c)

#### ***6.4.1 Site Description***

All of the subject sites were located in commercial or mixed commercial-residential settings; three in the state of Florida(S2, S3, S4) and one located in Oregon(S1). The contaminants identified in soil and/or groundwater samples included tetrachloroethene (PCE), trichloroethene (TCE), vinyl chloride, cis-1,2-dichloroethene, trans-1,2-dichloroethene and 1,1-dichloroethene. Site geology consisted of combinations of silts, clays, sands and limestones located at varying depths. The subject sites located in Florida had depths to groundwater ranging from 2 to 6 feet below ground surface whereas the Oregon site had groundwater depths at 15-20 feet below ground surface. The site specific data available is summarized Table 3.

#### ***6.4.2 Uncertainty Representation***

The PROMETHEE method utilizes a single number to represent each criteria entry and any uncertainty associated with that number is intrinsic in nature. Variability is not accounted for in cases where a range of values are provided, and professional judgement is required to determine what value should be used (lower or upper, median, mean). In the case of contaminant concentrations, site soil and groundwater sampling always provides a range of values and generally the highest value detected is selected as representative of the entire site. This practice, while providing a conservative estimate may be exaggerating the hazard level of that site.

Fuzzy PROMETHEE allows for the use of data in its available form. That is, any data that is provided as a range may be utilized “as-is” and data that is linguistic in nature (“approximately”, “several”) may be interpreted with a range in values. The associated uncertainties are then incorporated by treating the representative criteria entry as a trapezoidal fuzzy numbers,  $(m_l, m_u, \alpha, \beta)_{LR}$  where  $[m_l, m_u]$  is the certainty interval, i.e. the membership value is equal to 1, with  $m_l$  and  $m_u$  as lower and upper boundaries, respectively.  $\alpha$  and  $\beta$  are the left and right spread of the trapezoidal fuzzy number. When  $m_l = m_u$ , a trapezoidal fuzzy number becomes a triangular fuzzy number. A crisp number



can be represented as  $m_l = m_u = n$  and  $\alpha = \beta = 0$  and an interval is represented as  $[m_l, m_u]$  and  $\alpha = \beta = 0$ .

**Table 6-3 Original site information**

| Site properties                            | Contaminated Site  |              |  |              |   |              |   |              |
|--|--|--------------|--|--------------|---|--------------|---|--------------|
|  | S1   |              | S2   |              | S3  |              | S4  |              |
| Contaminants                               | Soil (mg/kg)   | Water (mg/L) | Soil (mg/kg)   | Water (mg/L) | Soil (mg/kg)  | Water (mg/L) | Soil (mg/kg)  | Water (mg/L) |
|  |  |              |  |              |   |              |   |              |
| Tetrachloroethene (PCE)                    | >1000  | 2.60         | 2.88   | 0.0052       | 0.92  | 0.053        | 0.0372  | 42           |
| cis-1,2-Dichloroethene                     | 0.0002   | 3.00         | 1.43   | 0.546        | 0.0002  | 0.0039       | 0.00122   | 170          |
| trans-1,2-Dichloroethene                   | 0.0002   | 0.39         | 0.0002   | 0.0002       | 0.0002  | 0.0002       | 0.0002  | 0.260        |
| Trichloroethene (TCE)                      | 0.0002   | 0.53         | 0.0962   | 0.0045       | 0.0002  | 0.004        | 0.0032  | 12           |
| Vinyl Chloride                             | 0.0002   | 0.033        | 0.0108   | 1.100        | 0.0002  | 0.001        | 0.0002  | 59           |
|  |  |              |  |              |   |              |   |              |
| Property Use / Zoning                      | Commercial   |              | Residential<br>Commercial  |              | Residential<br>Commercial   |              | Commercial  |              |
| Depth to Groundwater (ft bgs)              | 15-20  |              | 2-4  |              | ~5  |              | 6   |              |
| Deepest Groundwater Contamination (ft bgs) | ~30  |              | 16   |              | 12  |              | 75  |              |
| Lithology and Subsurface Geology           | Clayey silt and fine sand (0-15ft); sandy gravel (15-45ft); basalt (>45ft) |              | Fine-grained silty sands with some clay (<48ft); sandy clay with silt & shell fragments (48-53 ft) |              | Fine to med sand (<5ft); weathered limestone (5-8ft); med-coarse sand and limestone gravel (15-25 ft) |              | Fine to med quartz sand with limestone stringers (<46ft); fine to med sand (46-62ft); coquina (62-68ft); fine sand and sandstone with limestone stringers (68-84ft) |              |
| Conductivity (ft/day)                      | 22-491   |              | 0.6-2.4  |              | 105   |              | 92  |              |
| Plume Size                                 | Several hundred feet long, 100 ft wide, 30 ft deep                         |              | 125 ft × 35 ft   |              | 80ft × 60 ft × 12 ft  |              | 1350 ft × 1000 ft   |              |

### ***6.4.3 Evaluation of criteria performance***

The optimization of each criterion is determined based on its potential influence on human and ecological risk. Criteria 1-2, Criteria 4-10 and Criteria 12 are all to be maximized as the higher the value the higher the potential risk. Criteria 3 and 11 are to be minimized since the highest associated potential risk occurs when the numerical values are small. For example, Criteria 3 (Partition Index) represents the tendency for contaminants to bind to soil rather than enter into water. Thus, the higher the  $K_d$  value the less risk associated with groundwater contamination. Since protection of groundwater is a priority, the lower the  $K_d$  value the higher the hazard associated with the site and Criteria 3 should be minimized. The data used to evaluate the criteria performance are given in Table 6-4 and Table 6-5; PROMETHEE and Fuzzy PROMETHEE, respectively. The original data provided in Table 6-3 are a combination of crisp values (singletons) and ranges.

For the conventional PROMETHEE method, the crisp values were used as reported whereas the ranges were modified based on professional judgement; the shallowest depth to ground water was selected due to the greater potential risk for contaminant infiltration, and the average conductivity were used.

For the Fuzzy PROMETHEE evaluation, where crisp values are provided, a triangular fuzzy number is assumed with the most likely range being  $\pm 10\%$  of the crisp value. Wherever ranges are provided,  $\alpha = 0.1 m_l$  and  $\beta = 0.1 m_u$  were used. This was done assuming that even though single values (or ranges) are reported, the actual field data will vary by  $\pm 10\%$  of the reported values. If all of the data were available, however, the minimum and maximum values obtained from the samples analyzed would be utilized to more accurately represent the conditions at the site under investigation.

**Table 6-4 PROMETHEE Criteria Evaluations**

|    | Criteria                                     | Max<br>or Min | Contaminated Sites (Actions) |         |        |          | Preference<br>Parameter<br><i>p</i> |
|----|--|---------------|------------------------------|---------|--------|----------|-------------------------------------|
|    |  |               | S1                           | S2      | S3     | S4       |                                     |
| 1  | Soil Carcinogenic Risk Index (SCRI)          | Max           | 324                          | 0.954   | 0.298  | 12.45    | 323.7                               |
| 2  | Soil Non-Carcinogenic Risk Index (SNCRI)     | Max           | 83333.3                      | 495.918 | 76.667 | 6994.73  | 83256.7                             |
| 3  | Partition Index (PI) (l/kg)                  | Min           | 384.62                       | 362.42  | 17.342 | 0.812    | 383.8                               |
| 4  | Volume Contaminated Soil (ft <sup>3</sup> )  | Max           | 210000                       | 70000   | 57600  | 10125000 | 101192400                           |
| 5  | Volume Contaminated Water (ft <sup>3</sup> ) | Max           | 105000                       | 61250   | 33600  | 9315000  | 93116400                            |
| 6  | Percentage of Permeable Groundcover          | Max           | 18                           | 18      | 18     | 90       | 65                                  |
| 7  | Exposure Index, EI                           | Max           | 68.18                        | 95.46   | 95.46  | 68.18    | 27.27                               |
| 8  | Vapor Pressure Index(mm Hg)                  | Max           | 18.35                        | 86.33   | 18.33  | 27.42    | 68.0                                |
| 9  | Total GUS (Groundwater Ubiquity Score Index) | Max           | 37.09                        | 28.93   | 28.93  | 37.09    | 8.16                                |
| 10 | Hydraulic Conductivity                       | Max           | 256                          | 1.5     | 105    | 92       | 254.5                               |
| 11 | Ecological Toxicity Index (ETI)              | Min           | 14                           | 179     | 14     | 119      | 165                                 |
| 12 | Biocentrations Index (BCI)                   | Max           | 2.25                         | 7.46    | 2.25   | 5.90     | 5.21                                |

**Table 6-5: Fuzzy PROMETHEE Criteria Evaluations**

|          |  | Max<br>or<br>Min | Contaminated Sites (Actions)       |                                 |                              |  | Preference<br>Parameter,<br><i>p</i> |
|----------|--|------------------|------------------------------------|---------------------------------|------------------------------|--|--------------------------------------|
| Criteria |  |                  | S1                                 | S2                              | S3                           | S4   |                                      |
| 1        | Soil Carcinogenic Risk Index (SCRI)          | Max              | [324, 324, 87.8, 107.2]            | [0.94, 0.97, 0.25, 0.32]        | [0.3, 0.3, 0.08, 0.1]        | [12.05, 12.85, 3.27, 4.25]                 | 431                                  |
| 2        | Soil Non-Carcinogenic Risk Index (SNCRI)     | Max              | [71429, 100000, 13571, 21000]      | [418.21, 755.27, 79.46, 158.61] | [65.71, 92, 12.49, 19.32]    | [5053.12, 14908.67, 960.1, 3130.8]         | 120988.62                            |
| 3        | Partition Index (PI) (l/kg)                  | Min              | [384.62, 384.62, 132.27, 178.5]    | [362.42, 362.42, 124.64, 168.2] | [17.34, 17.34, 5.96, 8.05]   | [0.81, 0.81, 0.28, 0.38]                   | 562.59                               |
| 4        | Volume Contaminated Soil (ft <sup>3</sup> )  | Max              | [1250000, 3150000, 237500, 661500] | [70000, 70000, 13300, 14700]    | [57600, 57600, 10944, 12096] | [101250000, 101250000, 19237500, 21262500] | 122465844                            |
| 5        | Volume Contaminated Water (ft <sup>3</sup> ) | Max              | [250000, 1800000, 205000, 724500]  | [52500, 61250, 12337, 15750]    | [28800, 38400, 9792, 13344]  | [93150000, 93150000, 19156500, 21343500]   | 114474492                            |
| 6        | Percentage of Permeable Groundcover          | Max              | [1, 35, 0.1, 3.5]                  | [1, 35, 0.1, 3.5]               | [1, 35, 0.1, 3.5]            | [90, 90, 9, 9]                             | 98.1                                 |
| 7        | Exposure Index (EI)                          | Max              | [68.18, 88.4, 6.82, 8.84]          | [68.18, 148.52, 6.82, 14.85]    | [68.18, 148.52, 6.82, 14.85] | [68.18, 88.40, 6.82, 8.84]                 | 102.01                               |
| 8        | Vapor Pressure Index (mm Hg)                 | Max              | [18.2, 18.5, 4.93, 6.12]           | [84.73, 88.3, 22.96, 29.23]     | [18.18, 18.48, 4.93, 6.12]   | [26.79, 28.48, 7.26, 9.43]                 | 104.28                               |
| 9        | Total GUS                                    | Max              | [38.01, 38.01, 3.8, 3.8]           | [29.85, 29.85, 2.99, 2.99]      | [29.85, 29.85, 2.99, 2.99]   | [38.01, 38.01, 3.8, 3.8]                   | 14.95                                |
| 10       | Hydraulic Conductivity                       | Max              | [22, 491, 2.2, 49.1]               | [0.6, 2.4, 0.06, 0.24]          | [105, 105, 10.5, 10.5]       | [92, 92, 9.2, 9.2]                         | 539.56                               |
| 11       | Ecological Toxicity Index (ETI)              | Min              | [11,17,1.1,1.7]                    | [156,225,15.6,22.5]             | [11,17,1.1,1.7]              | [102,139,10.2,13.9]                        | 237.6                                |
| 12       | Biocentration Index (BCI)                    | Max              | [2.09, 2.42, 0.21, 0.24]           | [6.79, 8.00, 0.68, 0.80]        | [2.09, 2.42, 0.21, 0.24]]    | [5.36, 6.32, 0.54, 0.63]                   | 6.92                                 |

#### 6.4.4 Results and discussion

Two computer programs in EXCEL<sup>®</sup> were written to implement the PROMETHEE and the Fuzzy PROMETHEE methods.

Using the PROMETHEE program developed and “crisp” data from Table 6-3, each of the criteria identified in Section 6.2 were determined (Table 6-4). The preferences for each criterion were evaluated, summed and weighted to obtain the preference indices for each site. As all the criteria were considered to be of equal importance, an equal weighting was assumed for each criteria. These values are placed in a preference index table indicating the preference of one site over the other (Table 6-6).

**Table 6-6 PROMETHEE Preference Indices**

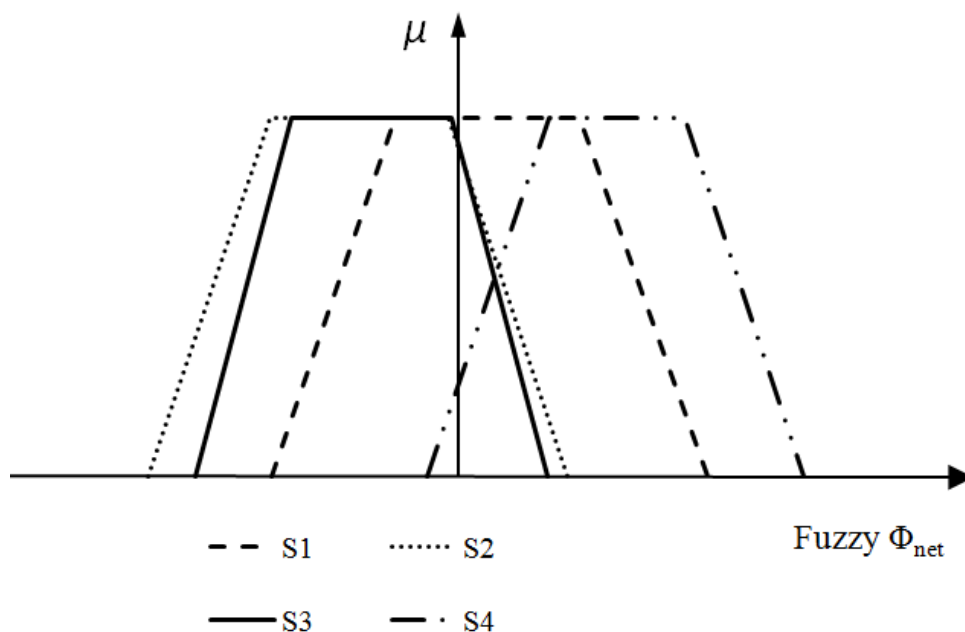
| $\pi(S_i, S_j)$ | S1    | S2    | S3    | S4    | $\phi^+$ | $\phi_{\text{net}}$ | Rank |
|-----------------|-------|-------|-------|-------|----------|---------------------|------|
| S1              | -     | 0.419 | 0.302 | 0.263 | 0.328    | 0.055               | 2    |
| S2              | 0.255 | -     | 0.167 | 0.180 | 0.201    | -0.163              | 4    |
| S3              | 0.163 | 0.192 | -     | 0.141 | 0.165    | -0.130              | 3    |
| S4              | 0.400 | 0.481 | 0.416 | -     | 0.433    | 0.238               | 1    |
| $\phi^-$        | 0.273 | 0.364 | 0.295 | 0.195 |          |                     |      |

For example, S1 is preferred over S2 by 0.419 whereas S2 is preferred over S1 by 0.255. The total leaving and entering flows provides a measure of outranking and outranked characteristics for each of the contaminated sites and are obtained by averaging the sum the preference index values in the rows and columns, respectively. The net flow ( $\Phi^{\text{net}}$ ) provides the overall outranking characteristic of the site and is the resultant difference of  $\Phi^+$  and  $\Phi^-$ . The greater the leaving flow and the lesser the entering flow, the greater the net flow and hence the higher the overall preference of the alternative. A negative net flow can be obtained and is indicative of an alternative that is primarily outranked by all

other alternatives for each criterion. Final ranking is then achieved by a numerical sort from highest to lowest net flow. The results for the Traditional PROMETHEE method are also presented in Table 6-6

Using the Fuzzy PROMETHEE program developed and trapezoidal/triangular representations of the data provided in Table 6-3, each of the criteria identified in Section 6.2 were determined and placed in Table 6-5. The same procedure was followed as for the traditional method to obtain the preference indices, leaving and entering flows. The results are presented in Table 6-7.

The fuzzy net flow for each contaminated site is illustrated below:



**Figure 6—1: Fuzzy Net Flows**

**Table 6-7: Fuzzy PROMETHEE Preference Indices and defuzzified entering, leaving, and net flow**

| $\pi(S_i, S_j)$     | S1                               | S2                                | S3                                | S4                              | $\phi_{\sim}^+$                 | $\phi_{\text{net}}$ | Rank |
|---------------------|----------------------------------|-----------------------------------|-----------------------------------|---------------------------------|---------------------------------|---------------------|------|
| S1                  | -                                | [0.209, 0.376,<br>0.071, 0.147]   | [0.158, 0.292,<br>0.064, 0.114]   | [0.129, 0.249,<br>0.033, 0.110] | [0.165, 0.306,<br>0.056, 0.124] | 0.039               | 2    |
| S2                  | [0.109, 0.225,<br>0.038, 0.105]  | -                                 | [0.106, 0.222, 0.034,<br>0.094]   | [0.051, 0.147,<br>0.031, 0.067] | [0.088, 0.198,<br>0.034, 0.089] | -0.132              | 4    |
| S3                  | [0.054, 0.168,<br>0.021, 0.065]  | [0.116, 0.237,<br>0.027, 0.090]   | -                                 | [0.032, 0.112,<br>0.006, 0.030] | [0.067, 0.172,<br>0.018, 0.062] | -0.114              | 3    |
| S4                  | [0.279, 0.355,<br>0.074, 0.143]  | [0.307, 0.397,<br>0.103, 0.140]   | [0.279, 0.349,<br>0.094, 0.115]   | -                               | [0.289, 0.367,<br>0.090, 0.133] | 0.207               | 1    |
| $\phi_{\sim}^-$     | [0.147, 0.249,<br>0.044, 0.104]  | [0.211, 0.337,<br>0.067, 0.126]   | [0.181, 0.288,<br>0.064, 0.108]   | [0.071, 0.169,<br>0.024, 0.069] |                                 |                     |      |
| $\phi_{\text{net}}$ | [-0.084, 0.158,<br>0.161, 0.168] | [-0.248, -0.013,<br>0.160, 0.156] | [-0.221, -0.008,<br>0.126, 0.126] | [0.119, 0.296,<br>0.159, 0.156] |                                 |                     |      |

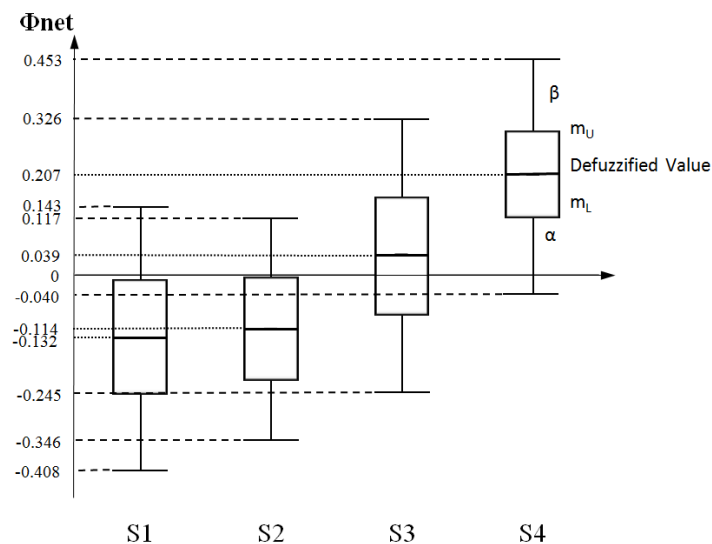


Several approaches have been proposed for ranking fuzzy numbers (Detyniecki and Yager 2001; Dubois and Prade 1999; Lee et al. 1994; Wang et al. 2005) with the most of them transforming the fuzzy number into a real number. The Center-of-Area (COA) approach compared to the Mean-of-Maximum or Maxima-Method provides a more consistent evaluation of trapezoidal/triangular fuzzy data and crisp data (Geldermann et al. 2000). The COA method was selected for defuzzification of the resulting fuzzy entering and leaving flows and is computed as follows:

**Equation 6–29: Defuzzification via Center-of-Area**

$$x_{\text{defuzzified}} = \frac{\int x\mu(x)dx}{\int \mu(x)dx} = \frac{m_u^2 - m_l^2 + \alpha m_l + \beta m_u + (\beta^2 - \alpha^2)/3}{\alpha + \beta + 2m_u - 2m_l}$$

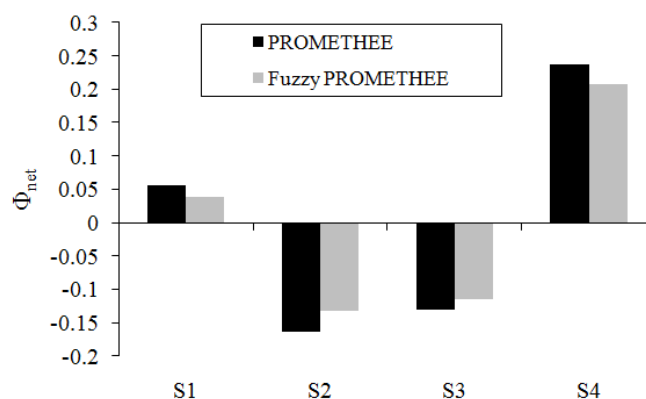
where  $\mu$  is the membership function for a trapezoidal fuzzy number (Geldermann et al. 2000). The defuzzified total leaving and entering flows are provided in Table 6-7 along with the final net flows and subsequent ranking of the subject sites. The ranking results and the associated uncertain information pertaining to each contaminated site are graphically represented using box-and-whisker plots (Figure 6—2 ).



**Figure 6—2: Fuzzy Net Flow Box-and-Whisker Plots**

The outrankings obtained for these four sites based on PROMETHEE II and Fuzzy PROMETHEE II were the same:  $S4 \rightarrow S1 \rightarrow S3 \rightarrow S2$ , where S4 was ranked first (highest potential hazard) and S2 was ranked last (least potential hazard). Examination of the original data would intuitively provide the same result as S4 has in essence the highest contaminant concentration in soil and groundwater, the highest concentration of a known human carcinogen present in an extremely large sized plume that is close to the surface and contamination that reaches to great depths. Information for S4 from the State Coalition for Remediation of Dry Cleaning Sites also indicated that the facility had been demolished so a 100% permeable surface was assumed. S1 has the next highest concentration of contaminants present in both soil and groundwater, the next largest plume size, the next largest deepest groundwater contamination but larger depth to groundwater from surface. At first glance the parameter values for S2 & S3 would tend to indicate S2 to be more potentially hazardous than S3. However, closer examination would reveal that S3 could be more potentially hazardous based on contaminant transport phenomena. Thus, S2 and S3 are considered close in rank and depending on the interpretation of the data by the decision maker the final ranking could be either  $S3 \rightarrow S2$  or  $S2 \rightarrow S3$ .

The final net flow values obtained for the Fuzzy PROMETHEE and the traditional PROMETHEE methods are provided in Figure 6—3 for comparison.



**Figure 6—3: Final New Flow**

The  $\Phi^{\text{net}}$  values obtained for the Traditional PROMETHEE and the Fuzzy PROMETHEE methods are similar, though not the same. This may be due to size of the data set and/or the high degree of similarity between the sites examined (same contaminants, same geographical regions, similar data reporting) given that the principle of PROMETHEE is based on comparative differences. While no pattern in net value shift between the traditional and fuzzy methodologies can be identified (i.e. fuzzy method providing consistently lower or higher net flow values than the traditional method) an interesting observation can be made regarding S2 and S3; the net flow values are much closer when Fuzzy PROMETHEE is utilized. This corresponds with the intuitive observations of the initial data where the ranking of S2 and S3 would be close. While this case may also indicate that the use of average values magnified the difference between the sites it is equally possible that using crisp data may artificially decrease the difference between sites. Thus, when there is substantial uncertainty in the data Fuzzy PROMETHEE should be preferred.

## 6.5 MODEL LIMITATIONS

During the creation of the twelve criteria for use in the PROMETHEE and Fuzzy PROMETHEE methods, several assumptions were made that may place certain limitations on the methodology presented:

1. The Ecological Toxicity Index, ETI (Criterion 11) uses the toxicity data for a specific indicator species (earthworm). Data is only available for approximately 90 chemicals and thus is limiting in its application depending on the chemicals identified at the site.
2. The Bioconcentration Index, BI (Criterion 12) uses a formula for contaminant concentration in plants (Equation 6–13) that may not be applicable in all locals. The equation selected was based on its applicability to multiple plant species from different published sources and the chemicals tested (Travis and Arms 1988). The species used may not be found in all locations and thus, may not be directly applicable.

3. The Bioconcentration Index, BI (Criterion 12) also relies on the use of earthworm data, and thus availability of information is limited (see Criterion 11 comments).

## 6.6 CONCLUSIONS

A flexible and simple multicriteria ranking system for contaminated sites based on comparative risk methodology was presented. Twelve criteria considered to be integral contributors in the process of hazard ranking were identified and developed based on the combination of attributes (toxicity, exposure, and receptors) associated with the potential human health and ecological risks of contaminated sites, site- and chemical-specific properties and contaminant transport phenomena. Both the PROMETHEE and fuzzy PROMETHEE methods were used to compare the sites and provided comparable results in terms of rank position. The selection of the methodology is dependent upon the type of data available; when the input data are numeric and crisp the PROMETHEE method can be used, whereas the Fuzzy PROMETHEE method can be used when substantial uncertainties and subjectivities exist in site information.

## CHAPTER SEVEN: CONCLUSION

### 7.1 GENERAL

This research investigated the various methods currently employed in the area of decision making for contaminated site management. They range from simple scoring systems to more complex multi-criteria models. The common feature of all the systems is that they are based on a source-pathway-receptor mode of analysis. The depth and complexity of the assessment and the amount of data required to estimate the level of risk is dependent on the particular site. As all properties are not identical, a phased approach is recommended by the Canadian government for contaminated site assessments with each successive phase increasing in detail of analysis. The phased approach also provides a means of effectively and efficiently allocating limited resources to those properties that require more attention, and reducing the time required characterizing the risks. The results of the assessments may be qualitative, semi-quantitative or quantitative in nature depending on the approach invoked.

The framework developed for the identifying and prioritizing contaminated sites for action consists of a multi-layer model wherein the first level provides a coarse means of assessment followed by a more refined, more detailed investigation and analysis in the subsequent levels. This model incorporated several methodologies to accomplish the goal of a user-friendly, scientifically defensible decision support system.

Level 1 of the multi-level Decision Support System Model framework involves the identification, classification and ranking of sites for Phase I Environmental Site Assessments. The model incorporates the source-pathway-receptor mode of analysis with the functionality of a rule-based system and a comparative system to classify and rank the sites in order to prioritize the actions to be taken. The methodology is designed to compare a large number of sites with a vast amount of data on several criteria. The case study presented validated the Level 1 methodology.

Level 3 of the DSS incorporated the traditional human health and ecological health risk assessment paradigms with political, regulatory compliance and cost to classify and prioritize those sites that require further action. When working with multiple criteria, the difficulty encountered in combining the results stems from the meaning of the output obtained. For example, the potential human impact factor combines the results of carcinogenic risk with non-carcinogenic risk by transforming the output into a common scale based on scientific evidence/values. Without transforming these values, there is no method of comparing the outcomes. Carcinogenic risk is represented as a probability of developing cancer in a lifetime, whereas non-carcinogenic risk is an indication of potential adverse effects occurring. Which of these should take priority when a decision is made and how is that decision to be supported? Linear transformation of the output of the related criteria provides a simple, transparent means of assessing a site.

The last chapter of this work introduced an alternative method for contaminated site ranking, Fuzzy PROMETHEE. The method was tested using data from dry cleaner sites and was deemed a viable option. Further testing of the method using municipal sites from the Level 3 case study was not performed as more ecological criteria have been identified since the Fuzzy PROMETHEE model was developed and result comparisons would be ineffective.

Currently there is no universal classification and ranking system that Municipal Environmental Site Managers can use as a decision support system. Making a decision is not just a selecting the best alternative, it needs to combine the strength of the individual criteria in order to produce a rank that can ultimately be used for the efficient allocation of resources. This research has produced a viable, scientifically defensible, transparent, methodology that incorporates several approaches into one user-friendly decision support system. This methodology will be extremely beneficial for site managers.

## **7.2 RECOMMENDATIONS FOR FURTHER WORK**

1. Further research into the selection of remedial actions would be beneficial in developing the cost impact factor component of the DSS. If a system could be modeled to actively select a particular action(s) based on the site-specific conditions, Municipal Environmental Site Managers would be able to estimate the costs associated with the actions required for a given site. This would facilitate budget planning and resource allocation for the coming fiscal years.
2. While the model developed through this work has incorporated a number of methodologies into a single working multi-level multi-criteria decision support system, advances in risk assessment is resulting in the production of more governmental guidance documents. Generic guidelines may need to be incorporated into the system as they are generated.
3. An alternative methodology for classification and ranking of contaminated sites was provided in Chapter 7 that utilized Fuzzy PROMETHEE. While the method is a viable alternative, further work needs to be done to refine existing environmental criteria and incorporate more of the environmental criteria identified in the multi-level multi-criteria decision support system developed as well as the political and cost factors.

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**APPENDIX A: SCREENED DATA - LEVEL 1 CASE STUDY**

**Table A 1: Spatial Property Descriptors**

| Site # | Screening Date |  |  | Unique Property ID | Parcel Section | Community | Ward | Surface Area (m <sup>2</sup> ) | Land Use (LUD) |     |     | Property Use (PUD) |      |     |
|--------|----------------|--|--|--------------------|----------------|-----------|------|--------------------------------|----------------|-----|-----|--------------------|------|-----|
|        |                |  |  |                    |                |           |      |                                | 1              | 2   | 3   | 1                  | 2    | 3   |
| 1      | 10 Aug 2006    |  |  | 91202              | 1 of 1         | CDGIP     | E    | 2956                           | PE             | n/a | n/a | RES                | n/a  | n/a |
| 2      | 17 Aug 2006    |  |  | 53864              | 1 of 1         | CDW       | G    | 2031                           | DC             | n/a | n/a | MR                 | n/a  | n/a |
| 3      | 13 Sep 2006    |  |  | 94125              | 1 of 1         | CDO       | K    | 167                            |                |     |     |                    |      |     |
| 4      | 19 Sep 2006    |  |  | 78091              | 1 of 1         | CDO       | K    | 19                             |                |     |     |                    |      |     |
| 5      | 30 Nov 2006    |  |  | 94617              | 1 of 1         | CDFI      | K    | 15                             |                |     |     |                    |      |     |
| 6      | 17 Nov 2006    |  |  | 40494              | 1 of 1         | CDWP      | M    | 5677                           | R-2            | n/a | n/a | INST               | n/a  | n/a |
| 7      | 27 Nov 2006    |  |  | 30427              | 1 of 1         | CDBR      | K    | 278                            | RM-4           | n/a | n/a | REC                | n/a  | n/a |
| 8      | 27 Nov 2006    |  |  | 8293               | 1 of 1         | CDBR      | K    | 278                            | RM-4           | n/a | n/a | REC                | n/a  | n/a |
| 9      | 01 Dec 2006    |  |  | 58628              | 1 of 1         | CDBR      | K    | 13131                          | DC             | n/a | n/a | MRES               | COM  | n/a |
| 10     | 11 Oct 2006    |  |  | 676                | 1 of 1         | CDMI      | K    | 2742                           | I-2            | n/a | n/a | RES                | n/a  | n/a |
| 11     | 25 Oct 2006    |  |  | 66685              | 1 of 1         | CDRW2     | C    | 255608                         | UR             | n/a | n/a | INST               | AGR  | IND |
| 12     | 13 Nov 2006    |  |  | 4329               | 1 of 2         | CDRW1     | A    | 173293                         | DC             | n/a | n/a | INST               | n/a  | n/a |
| 13     | 13 Nov 2006    |  |  | 4330               | 2 of 2         | CDRW1     | A    | 619580                         | DC             | n/a | n/a | IND                | INST | n/a |
| 14     | 29 Nov 2006    |  |  | 63493              | 1 of 1         | CDE       | K    | 1351                           | R-2            | n/a | n/a | ER                 | n/a  | n/a |
| 15     | 29 Aug 2006    |  |  | 54174              | 1 of 2         | CDBI      | K    | 490                            | I-2            | n/a | n/a | RES                | n/a  | n/a |
| 16     | 29 Sep 2006    |  |  | 91371              | 1 of 1         | CDGIP     | E    | 308571                         | I-2            | n/a | n/a | IND                | n/a  | n/a |
| 17     | 13 Dec 2006    |  |  | 74947              | 1 of 1         | CDG       | I    | 5531                           | RM-4           | n/a | n/a | MRES               | n/a  | n/a |

**Table A 2: Environmental Report Review**

| Site # | Onsite            |   | Offsite (within 100m) |   |              |
|--------|-------------------|---|-----------------------|---|--------------|
|        | Report Completed? | Most Detailed Report                      | Report Completed?     | Most Detailed Report                      | Distance (m) |
| 1      | No                | n/a                                       | No                    | n/a                                       | n/a          |
| 2      | No                | n/a                                       | No                    | n/a                                       | n/a          |
| 3      |                   |   |                       |   |              |
| 4      |                   |   |                       |   |              |
| 5      |                   |   |                       |   |              |
| 6      | No                | n/a                                       | Yes                   | Remediation Plan                          | 64           |
| 7      | No                | n/a                                       | No                    | n/a                                       | n/a          |
| 8      | No                | n/a                                       | No                    | n/a                                       | n/a          |
| 9      | No                | n/a                                       | No                    | n/a                                       | n/a          |
| 10     | Yes               | Further Work / Supplemental Investigation | Yes                   | Remediation Plan                          | 20           |
| 11     | Yes               | Phase II ESA                              | Yes                   | Risk Management Plan                      | 0            |
| 12     | Yes               | Phase I & II Combined                     | Yes                   | Other reports                             | 18           |
| 13     | Yes               | Remediation Plan                          | Yes                   | Further Work / Supplemental Investigation | 0            |
| 14     | No                | n/a                                       | Yes                   | Phase I ESA                               | 15           |
| 15     | No                | n/a                                       | No                    | n/a                                       | n/a          |
| 16     | Yes               | Remediation Plan                          | Yes                   | Phase II ESA                              | 33           |
| 17     | No                | n/a                                       | no                    | n/a                                       | n/a          |





**Table A 4: Case Study – Potentially Contaminating Sources (Foreign Utilities)**

| Site # | Onsite  |              |           | Offsite (within 100m) |              |                      |                          |
|--------|---------|--------------|-----------|-----------------------|--------------|----------------------|--------------------------|
|        | Present | Utility Type | Well Type | Utility Type          | Type of Well | Distance to Well (m) | Distance to Pipeline (m) |
| 1      | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 2      | no      | n/a          | n/a       | pipeline(s)           | n/a          | n/a                  | 96                       |
| 3      |         |              |           |                       |              |                      |                          |
| 4      |         |              |           |                       |              |                      |                          |
| 5      |         |              |           |                       |              |                      |                          |
| 6      | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 7      | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 8      | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 9      | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 10     | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 11     | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 12     | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 13     | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 14     | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 15     | yes     | pipeline(s)  | n/a       | pipeline(s)           | n/a          | n/a                  | 0                        |
| 16     | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |
| 17     | no      | n/a          | n/a       | n/a                   | n/a          | n/a                  | n/a                      |

**Table A 5: Potentially Contaminating Activities (Onsite)**

| Site # | Total # Activities | Activity #1                               |                           |               | Activity #2       |                        | Activity #3       |                     |
|--------|--------------------|---|---------------------------|---------------|-------------------|------------------------|-------------------|---------------------|
|        |                    | Activity Category                         | Activity of Concern       | Activity Code | Activity Category | Activity of Concern    | Activity Category | Activity of Concern |
| 1      | 0                  | n/a                                       | n/a                       | n/a           | n/a               | n/a                    | n/a               | n/a                 |
| 2      | 0                  | n/a                                       | n/a                       | n/a           | n/a               | n/a                    | n/a               | n/a                 |
| 3      |                    |   |                           |               |                   |                        |                   |                     |
| 4      |                    |   |                           |               |                   |                        |                   |                     |
| 5      |                    |   |                           |               |                   |                        |                   |                     |
| 6      | 1                  | Petroleum Handling Systems                | Firehall                  | AUTO          | n/a               | n/a                    | n/a               | n/a                 |
| 7      | 0                  | n/a                                       | n/a                       | n/a           | n/a               | n/a                    | n/a               | n/a                 |
| 8      | 0                  | n/a                                       | n/a                       | n/a           | n/a               | n/a                    | n/a               | n/a                 |
| 9      | 1                  | Animal Processing & Fertilizer Production | Agricultural Chemicals    | FERT          | n/a               | n/a                    | n/a               | n/a                 |
| 10     | 1                  | Misc 2                                    | Railway                   | RAILT         | n/a               | n/a                    | n/a               | n/a                 |
| 11     | 1                  | Misc 2                                    | Controlled Waste Disposal | WEDUMP        | n/a               | n/a                    | n/a               | n/a                 |
| 12     | 1                  | Misc 2                                    | Sewage Treatment          | WEDUMP        | n/a               | n/a                    | n/a               | n/a                 |
| 13     | 2                  | Misc 2                                    | Sewage Treatment          | WEDUMP        | Misc 2            | Railway Tracks         | n/a               | n/a                 |
| 14     | 0                  | n/a                                       | n/a                       | n/a           | n/a               | n/a                    | n/a               | n/a                 |
| 15     | 0                  | n/a                                       | n/a                       | n/a           | n/a               | n/a                    | n/a               | n/a                 |
| 16     | 2                  | Petroleum Handling Systems                | City Transit Garage/Shop  | AUTO          | Misc 2            | Local Improvement Site | n/a               | n/a                 |
| 17     | 0                  | n/a                                       | n/a                       | n/a           | n/a               | n/a                    | n/a               | n/a                 |

**Table A 6: Potentially Contaminating Activities (Offsite within 100m)**

| Site # | Total # Activities | Activity #1  |                             |                             |               | Activity #2  |                             |                                   |
|--------|--------------------|--------------|-----------------------------|-----------------------------|---------------|--------------|-----------------------------|-----------------------------------|
|        |                    | Distance (m) | Activity Category           | Activity of Concern         | Activity Code | Distance (m) | Activity Category           | Activity of Concern               |
| 1      | 0                  | n/a          | n/a                         | n/a                         | n/a           | n/a          | n/a                         | n/a                               |
| 2      | 0                  | n/a          | n/a                         | n/a                         | n/a           | n/a          | n/a                         | n/a                               |
| 3      |                    |              |                             |                             |               |              |                             |                                   |
| 4      |                    |              |                             |                             |               |              |                             |                                   |
| 5      |                    |              |                             |                             |               |              |                             |                                   |
| 6      | 5                  | 31           | Petroleum handling systems  | Service station             | GAS           | 59           | Petroleum handling systems  | Service station                   |
| 7      | 2                  | 77           | Petroleum handling systems  | Service station             | GAS           | 77           | Misc 2                      | Lumber Manufacturing / Processing |
| 8      | 2                  | 81           | Petroleum handling systems  | Service station             | GAS           | 81           | Misc 2                      | Lumber Manufacturing / Processing |
| 9      | 3                  | 24           | Petroleum handling systems  | Service station             | GAS           | 21           | Misc 2                      | Lumber Manufacturing / Processing |
| 10     | 10                 | 89           | Petroleum handling systems  | Service station             | GAS           | 0            | Railway Operations          | Railway                           |
| 11     | 4                  | 0            | Misc 1                      | Sand/gravel pits & concrete | PIT           | 21           | Misc 1                      | Sand/gravel pits & concrete       |
| 12     | 2                  | 20           | Misc 2                      | Railway                     | RAILT         | 79           | Misc 2                      | Sewage treatment                  |
| 13     | 1                  | 20           | Misc 2                      | Railway                     | RAILT         | n/a          | n/a                         | n/a                               |
| 14     | 1                  | 51           | Dry Cleaners                | Laundry / Dry cleaning      | DRY           | n/a          | n/a                         | n/a                               |
| 15     | 1                  | 0            | Auto body shops & junkyards | Auto wreckers               | BODY          | 0            | Auto body shops & junkyards | Auto body shop                    |
| 16     | 9                  | 17           | Petroleum handling systems  | Shop/garage                 | AUTO          | 33           | Petroleum handling systems  | Shop/garage                       |
| 17     | 2                  | 23           | Petroleum handling systems  | Gas station                 | GAS           | 20           | Dry cleaners                | drycleaner                        |

**Table A 7: Potentially Contaminating Activities (Offsite within 100m) - Continued**

| Site # | Activity #3  |                            |                                   | Activity #4  |                             |                             |
|--------|--------------|----------------------------|-----------------------------------|--------------|-----------------------------|-----------------------------|
|        | Distance (m) | Activity Category          | Activity of Concern               | Distance (m) | Activity Category           | Activity of Concern         |
| 1      | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 2      | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 3      |              |                            |                                   |              |                             |                             |
| 4      |              |                            |                                   |              |                             |                             |
| 5      |              |                            |                                   |              |                             |                             |
| 6      | 64           | Petroleum handling systems | Service station                   | 30           | Auto body shops & junkyards | Auto bodyshop               |
| 7      | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 8      | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 9      | 24           | Misc 1                     | Lumber Manufacturing / Processing | n/a          | n/a                         | n/a                         |
| 10     | 0            | Misc 1                     | Plastics/Styrofoam                | 0            | Misc 1                      | Agricultural chemicals      |
| 11     | 21           | Misc 1                     | Sand/gravel pits & concrete       | 20           | Misc 2                      | Sand/gravel pits & concrete |
| 12     | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 13     | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 14     | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 15     | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |
| 16     | 25           | Misc 1                     | Steel Goods Manufacture           | 46           | Misc 1                      | Chemical Storage            |
| 17     | n/a          | n/a                        | n/a                               | n/a          | n/a                         | n/a                         |

**Table A 8: Potentially Contaminating Activities (Offsite within 100m) – Continued**

| Site # | Activity #5  |                             |                                    | Activity #6  |                             |                                    |
|--------|--------------|-----------------------------|------------------------------------|--------------|-----------------------------|------------------------------------|
|        | Distance (m) | Activity Category           | Activity of Concern                | Distance (m) | Activity Category           | Activity of Concern                |
| 1      | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 2      | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 3      |              |                             |                                    |              |                             |                                    |
| 4      |              |                             |                                    |              |                             |                                    |
| 5      |              |                             |                                    |              |                             |                                    |
| 6      | 31           | Misc 1                      | Wire/Wire Rope Industries          | n/a          | n/a                         | n/a                                |
| 7      | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 8      | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 9      | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 10     | 23           | Misc 1                      | Metal Manufacturing / Machine Shop | 39           | Misc 1                      | Metal Manufacturing / Machine Shop |
| 11     | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 12     | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 13     | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 14     | n/a          | n/a                         | n/                                 | n/a          | n/a                         | n/a                                |
| 15     | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |
| 16     | 30           | Auto body shops & junkyards | Auto body shop                     | 28           | Auto body shops & junkyards | Auto body shop                     |
| 17     | n/a          | n/a                         | n/a                                | n/a          | n/a                         | n/a                                |

**Table A 9: Geologic and Hydrogeologic Screening (Onsite)**

| <b>Site #</b> | <b>Surficial Geology</b> | <b># Waterbodies / Water wells</b> | <b>Type of Water body</b> | <b>Water Well Present</b> | <b>Type of Water Well</b> |
|---------------|--------------------------|------------------------------------|---------------------------|---------------------------|---------------------------|
| 1             | Gravel                   | 0                                  | n/a                       | No                        | n/a                       |
| 2             | Other                    | 0                                  | n/a                       | No                        | n/a                       |
| 3             |                          |                                    |                           |                           |                           |
| 4             |                          |                                    |                           |                           |                           |
| 5             |                          |                                    |                           |                           |                           |
| 6             | Sand                     | 0                                  | n/a                       | n/a                       | n/a                       |
| 7             | Gravel                   | 0                                  | n/a                       | No                        | n/a                       |
| 8             | Gravel                   | 0                                  | n/a                       | No                        | n/a                       |
| 9             | Gravel                   | 0                                  | n/a                       | No                        | n/a                       |
| 10            | Gravel                   | 0                                  | n/a                       | n/a                       | n/a                       |
| 11            | n/a                      | 45                                 | Wetland                   | Yes                       | Domestic                  |
| 12            | Gravel                   | 3                                  | Wetland                   | No                        | n/a                       |
| 13            | Gravel                   | 19                                 | Wetland                   | Yes                       | Undefined                 |
| 14            | Gravel                   | 0                                  | n/a                       | n/a                       | n/a                       |
| 15            | Gravel                   | 0                                  | n/a                       | n/a                       | n/a                       |
| 16            | Gravel                   | 0                                  | n/a                       | No                        | n/a                       |
| 17            | gravel                   | 0                                  | n/a                       | No                        | n/a                       |

**Table A 10: Geologic and Hydrogeologic Screening (Offsite within 100m)**

| Site # | Total # | Rivers / Creeks |              | Potable  |              | Agricultural / Recreational |              | Ecological |              | Other    |              |
|--------|---------|-----------------|--------------|----------|--------------|-----------------------------|--------------|------------|--------------|----------|--------------|
|        |         | Present         | Distance (m) | Quantity | Distance (m) | Quantity                    | Distance (m) | Quantity   | Distance (m) | Quantity | Distance (m) |
| 1      | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 2      | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 3      |         |                 |              |          |              |                             |              |            |              |          |              |
| 4      |         |                 |              |          |              |                             |              |            |              |          |              |
| 5      |         |                 |              |          |              |                             |              |            |              |          |              |
| 6      | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 7      | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 8      | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 9      | 0       | Yes             | 78           | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 10     | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 11     | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 12     | 8       | No              | n/a          |          |              | 0                           | n/a          | 7          | 0            | 1        | 43           |
| 13     | 12      | No              | n/a          | 1        | 73           | 0                           | n/a          | 11         | 0            | 0        | n/a          |
| 14     | 1       | Yes             | 4            | 1        | 4            | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 15     | 0       | No              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 16     | 1       | Yes             | 69           | 1        | 69           | 0                           | n/a          | 0          | n/a          | 0        | n/a          |
| 17     | 0       | no              | n/a          | 0        | n/a          | 0                           | n/a          | 0          | n/a          | 0        | n/a          |



**APPENDIX B: LEVEL 1 DSS ASSIGNED WEIGHTS**

**Table B 1: Preference Factor Assigned Weights**

| <b>Site Preference</b> | <b>Weight</b> |
|------------------------|---------------|
| On-Site                | 0.70          |
| Off-Site               | 0.30          |

**Table B 2: Property Use Ranking Assigned Weights**

| <b>Generalized Property Use Designation</b> | <b>Source Ranking</b> | <b>Receptor Ranking</b> |
|---|-----------------------|-------------------------|
| Agricultural                                | 0.4                   | 0.4                     |
| Commercial                                  | 1.0                   | 0.6                     |
| Environmental Reserve                       | 0.4                   | 0.4                     |
| Industrial                                  | 1.0                   | 0.0                     |
| Institutional                               | 0.6                   | 1.0                     |
| Linear Property                             | 0.4                   | 0.4                     |
| Multi-Residential                           | 0.4                   | 1.0                     |
| Municipal Reserve                           | 0.4                   | 0.4                     |
| Municipal School Reserve                    | 0.4                   | 0.4                     |
| Recreational                                | 0.6                   | 0.4                     |
| Residential                                 | 0.4                   | 1.0                     |
| Transportation                              | 0.6                   | 0.4                     |
| Foreign Utility Pipeline(s)                 | 0.6                   | 0.4                     |

**Table B 3: Land Use Ranking Assigned Weights**

| <b>Generalized Land Use Designation</b> | <b>Source Ranking</b> | <b>Receptor Ranking</b> |
|---|-----------------------|-------------------------|
| Low Density Residential                 | 0.4                   | 1.0                     |
| Medium/High Density Residential         | 0.4                   | 1.0                     |
| Commercial                              | 1.0                   | 0.6                     |
| Industrial                              | 1.0                   | 0.4                     |
| Agricultural & Open Space               | 0.4                   | 0.4                     |
| Direct Control                          | 0.6                   | 1.0                     |
| Public Park, School & Recreation        | 0.6                   | 0.6                     |
| Public Service                          | 0.6                   | 1.0                     |
| University Research                     | 0.4                   | 0.6                     |
| Urban Reserve                           | 0.4                   | 0.4                     |

**Table B 4: Potentially Contaminating Activity Assigned Weights**

| <b>PCA Category</b>         | <b>Weight</b> |
|-----------------------------|---------------|
| PCA1                        | 1.0           |
| PCA2                        | 0.6           |
| Tank1                       | 1.0           |
| Tank2                       | 0.6           |
| Foreign Utility Well(s)     | 1.0           |
| Foreign Utility Pipeline(s) | 0.6           |

**Table B 5: Waterbody Classification Assigned Weights**

| <b>Waterbody Classification</b> | <b>Weights</b> |
|---------------------------------|----------------|
| Potable                         | 1.0            |
| Agricultural/Recreational       | 0.7            |
| Ecological                      | 0.5            |
| Other                           | 0.4            |

**APPENDIX C: SCREENED DATA - LEVEL 3 CASE STUDY**

**Table C 1: Spatial Property Descriptors**

| Site | ADDRESS REVIEW |  |                                     |   | EXCEEDANCE | SOIL TYPE |
|------|----------------|--|-------------------------------------|---|------------|-----------|
|      | Report Date    |  | Site Surface Area (m <sup>2</sup> ) | Estimated Impact Area (m <sup>2</sup> ) | Reported   |           |
| 1    | 05 Jun 1997    |  | 34780                               | 2250                                    | Both       | Coarse    |
| 6    | 14 Feb 1996    |  | 18900                               | 525                                     | Both       | Fine      |
| 7    | 01 Dec 2004    |  | 8520                                | 8520                                    | Both       | Coarse    |
| 9    | 18 Nov 1997    |  | 3600                                | 3600                                    | Both       | Fine      |
| 10   | 18 Oct 1999    |  | 17480                               | 17480                                   | Soil       | Coarse    |
| 11   | 20 Mar 2002    |  | 90000                               | 90000                                   | Both       | Fine      |
| 13   | 30 Apr 2004    |  | 7000                                | 7000                                    | Both       | Coarse    |
| 15   | 30 Apr 2004    |  | 9350                                | 9350                                    | None       | Coarse    |
| 16   | 30 Apr 2004    |  | 11000                               | 11000                                   | Both       | Coarse    |
| 17   | 30 Apr 2004    |  | 5500                                | 5500                                    | None       | Coarse    |
| 18   | 08 Feb 1995    |  | 34780                               | 2250                                    | Both       | Coarse    |
| 19   | 06 Apr 2005    |  | 3620                                | 3620                                    | Soil       | Coarse    |
| 20   | 06 Apr 2005    |  | 2640                                | 2640                                    | Soil       | Coarse    |
| 21   | 24 Jun 1997    |  | 24268                               | 3500                                    | Both       | Coarse    |
| 22   | 05 Aug 2004    |  | 4050                                | 4050                                    | Both       | Coarse    |
| 23   | 01 Sep 2005    |  | 8050                                | 8050                                    | Both       | Coarse    |
| 27   | 11 Jan 2002    |  | 146000                              | 146000                                  | Water      | Fine      |
| 31   | 01 Feb 2006    |  | 6210                                | 6210                                    | Both       | Fine      |
| 37   | 12 Feb 1997    |  | 6888                                | 6888                                    | Soil       | Fine      |
| 44   | 01 Feb 2000    |  | 302175                              | 302175                                  | Both       | Coarse    |

**Table C 2: Property Zoning Review (Part 1)**

| Site | Subject Site              |                            |                                | North Site                |                            |                                | East Site                 |                            |                                |
|------|---------------------------|----------------------------|--------------------------------|---------------------------|----------------------------|--------------------------------|---------------------------|----------------------------|--------------------------------|
|      | AENV Generic Property Use | Land Use Designation (LUD) | Property Use Designation (PUD) | AENV Generic Property Use | Land Use Designation (LUD) | Property Use Designation (PUD) | AENV Generic Property Use | Land Use Designation (LUD) | Property Use Designation (PUD) |
| 1    | Commercial                | DC                         | commercial                     | Commercial                | C-C2                       | commercial                     | Commercial                | C-R3                       | commercial                     |
| 6    | Commercial                | C-C1                       | commercial                     | Residential/Parkland      | R-C2                       | single residential             | Residential/Parkland      | R-C2                       | single residential             |
| 7    | Commercial                | S-CRI                      | transportation                 | Commercial                | C-C1                       | commercial                     | Industrial                | I-G                        | industrial                     |
| 9    | Commercial                | n/a                        | n/a                            | Agricultural              | S-FUD                      | agricultural                   | Agricultural              | S-TUC                      | agricultural                   |
| 10   | Commercial                | C-C1                       | commercial                     | Residential/Parkland      | M-CG                       | single residential             | Commercial                | C-C1                       | commercial                     |
| 11   | Residential/Parkland      | C-COR2                     | single residential             | Residential/Parkland      | S-R                        | recreational                   | Residential/Parkland      | C-COR2                     | single residential             |
| 13   | Residential/Parkland      | M-CG                       | multiresidential               | Residential/Parkland      | R-C2                       | single residential             | Residential/Parkland      | S-UN                       | environmental reserve          |
| 15   | Residential/Parkland      | DC                         | multiresidential               | Residential/Parkland      | DC                         | multiresidential               | Residential/Parkland      | S-UN                       | recreational                   |
| 16   | Residential/Parkland      | DC                         | multiresidential               | Residential/Parkland      | DC                         | multiresidential               | Residential/Parkland      | S-UN                       | recreational                   |
| 17   | Residential/Parkland      | DC                         | multiresidential               | Residential/Parkland      | DC                         | multiresidential               | Residential/Parkland      | S-UN                       | recreational                   |
| 18   | Commercial                | C-COR3                     | commercial                     | Commercial                | C-C2                       | commercial                     | Commercial                | C-R3                       | commercial                     |
| 19   | Commercial                | C-COR3                     | commercial                     | Commercial                | C-COR3                     | commercial                     | Commercial                | S-CRI                      | transportation                 |
| 20   | Commercial                | C-COR3                     | commercial                     | Residential/Parkland      | R-C2                       | single residential             | Residential/Parkland      | R-C2                       | single residential             |
| 21   | Commercial                | C-C2                       | commercial                     | Commercial                | C-C2                       | commercial                     | Commercial                | DC                         | institutional                  |
| 22   | Industrial                | S-FUD                      | industrial                     | Residential/Parkland      | S-SPR                      | recreational                   | Residential/Parkland      | S-SPR                      | recreational                   |
| 23   | Residential/Parkland      | M-CG                       | multiresidential               | Residential/Parkland      | S-SPR                      | municipal reserve              | Residential/Parkland      | S-R                        | recreational                   |
| 27   | Agricultural              | n/a                        | n/a                            | Agricultural              | n/a                        | n/a                            | Agricultural              | n/a                        | n/a                            |
| 31   | Commercial                | S-CRI                      | commercial                     | Commercial                | S-CRI                      | commercial                     | Commercial                | S-CRI                      | commercial                     |
| 37   | Commercial                | S-CRI                      | institutional                  | Commercial                | C-N2                       | commercial                     | Residential/Parkland      | R-C1                       | single residential             |
| 44   | Industrial                | DC                         | industrial                     | Industrial                | DC                         | industrial                     | Industrial                | I-G                        | industrial                     |

**Table C 3: Property Zoning Review (Part 2)**

| Site | South Site                |                            |                                | West Site                 |                            |                                |
|------|---------------------------|----------------------------|--------------------------------|---------------------------|----------------------------|--------------------------------|
|      | AENV Generic Property Use | Land Use Designation (LUD) | Property Use Designation (PUD) | AENV Generic Property Use | Land Use Designation (LUD) | Property Use Designation (PUD) |
| 1    | Commercial                | C-R3                       | commercial                     | Residential/Parkland      | M-H2                       | single residential             |
| 6    | Commercial                | DC                         | commercial                     | Residential/Parkland      | R-C1                       | single residential             |
| 7    | Residential/Parkland      | R-C1                       | single residential             | Residential/Parkland      | R-C1                       | single residential             |
| 9    | Residential/Parkland      | N/A                        | n/a                            | Agricultural              | n/a                        | n/a                            |
| 10   | Residential/Parkland      | M-CG                       | multiresidential               | Residential/Parkland      | R-C1                       | single residential             |
| 11   | Residential/Parkland      | R-C2                       | single residential             | Residential/Parkland      | C-COR2                     | single residential             |
| 13   | Residential/Parkland      | S-SPR                      | municipal reserve              | Residential/Parkland      | R-C1                       | single residential             |
| 15   | Residential/Parkland      | DC                         | multiresidential               | Residential/Parkland      | R-C2                       | single residential             |
| 16   | Industrial                | I-H                        | industrial                     | Residential/Parkland      | R-C2                       | single residential             |
| 17   | Industrial                | I-H                        | industrial                     | Industrial                | DC                         | industrial                     |
| 18   | Commercial                | C-R3                       | commercial                     | Residential/Parkland      | M-H2                       | single residential             |
| 19   | Commercial                | C-COR3                     | commercial                     | Commercial                | C-COR2                     | industrial                     |
| 20   | Commercial                | C-COR3                     | commercial                     | Commercial                | S-CRI                      | transportation                 |
| 21   | Residential/Parkland      | S-SPR                      | recreational                   | Residential/Parkland      | R-C1                       | single residential             |
| 22   | Residential/Parkland      | S-R                        | recreational                   | Residential/Parkland      | S-R                        | recreational                   |
| 23   | Residential/Parkland      | R-C2                       | single residential             | Commercial                | C-COR3                     | commercial                     |
| 27   | Agricultural              | n/a                        | n/a                            | Residential/Parkland      | n/a                        | n/a                            |
| 31   | Commercial                | S-CRI                      | commercial                     | Commercial                | S-CRI                      | commercial                     |
| 37   | Residential/Parkland      | S-CI                       | institutional                  | Residential/Parkland      | R-C2                       | single residential             |
| 44   | Industrial                | I-G                        | industrial                     | Residential/Parkland      | S-CRI                      | institutional                  |



**Table C 4: Level 3 Hydrology**

| Site | Total # Waterbodies and Waterwells |                      |        |          |          |
|------|------------------------------------|----------------------|--------|----------|----------|
|      | Onsite                             | Potable Onsite<br>WW | 0-100m | 100-200m | 200-300m |
| 1    | 0                                  | No                   | 0      | 0        | 0        |
| 6    | 0                                  | No                   | 0      | 0        | 0        |
| 7    | 0                                  | No                   | 0      | 0        | 0        |
| 9    | 2                                  | Yes                  | 3      | 12       | 23       |
| 10   | 0                                  | No                   | 0      | 0        | 0        |
| 11   | 1                                  | No                   | 1      | 1        | 1        |
| 13   | 0                                  | No                   | 1      | 1        | 1        |
| 15   | 0                                  | No                   | 1      | 1        | 0        |
| 16   | 0                                  | No                   | 1      | 0        | 0        |
| 17   | 0                                  | No                   | 0      | 1        | 0        |
| 18   | 0                                  | No                   | 0      | 0        | 0        |
| 19   | 0                                  | No                   | 0      | 0        | 0        |
| 20   | 0                                  | No                   | 0      | 0        | 0        |
| 21   | 0                                  | No                   | 0      | 0        | 0        |
| 22   | 0                                  | No                   | 1      | 1        | 1        |
| 23   | 0                                  | No                   | 1      | 1        | 1        |
| 27   | 1                                  | No                   | 1      | 2        | 1        |
| 31   | 0                                  | No                   | 0      | 0        | 0        |
| 37   | 0                                  | No                   | 0      | 0        | 0        |
| 44   | 0                                  | No                   | 1      | 0        | 0        |

**Table C 5: Level 3 Sources & Activities**

| Site | Tanks |                | Potentially Contaminating Activity |                           |                            |     | Foreign Utility Type |
|------|-------|----------------|------------------------------------|---------------------------|----------------------------|-----|----------------------|
|      | AST   | UST or Unknown | Most Risky                         | 2nd                       | 3rd                        | 4th |                      |
| 1    | 0     | 4              | petroleum handling systems         | n/a                       | n/a                        | n/a | n/a                  |
| 6    | 0     | 4              | petroleum handling systems         | n/a                       | n/a                        | n/a | n/a                  |
| 7    | 0     | 0              | n/a                                | n/a                       | n/a                        | n/a | n/a                  |
| 9    | 3     | 2              | petroleum handling systems         | n/a                       | n/a                        | n/a | n/a                  |
| 10   | 0     | 4              | petroleum handling systems         | n/a                       | n/a                        | n/a | n/a                  |
| 11   | 0     | 0              | n/a                                | n/a                       | n/a                        | n/a | n/a                  |
| 13   | 0     | 0              | misc 1                             | n/a                       | n/a                        | n/a | n/a                  |
| 15   | 0     | 0              | n/a                                | n/a                       | n/a                        | n/a | n/a                  |
| 16   | 0     | 0              | n/a                                | n/a                       | n/a                        | n/a | n/a                  |
| 17   | 0     | 0              | n/a                                | n/a                       | n/a                        | n/a | n/a                  |
| 18   | 0     | 4              | petroleum handling systems         | n/a                       | n/a                        | n/a | n/a                  |
| 19   | 0     | 0              | n/a                                | n/a                       | n/a                        | n/a | n/a                  |
| 20   | 0     | 0              | misc 2                             | n/a                       | n/a                        | n/a | n/a                  |
| 21   | 0     | 6              | petroleum handling systems         | petroleum handling system |                            | n/a | n/a                  |
| 22   | 11    | 5              | petroleum handling systems         | misc 2                    | autobody shops & junkyards |     | n/a                  |
| 23   | 7     | 0              | misc 2                             | misc 2                    | n/a                        | n/a | n/a                  |
| 27   | 0     | 0              | misc 2                             | n/a                       | n/a                        | n/a | n/a                  |
| 31   | 0     | 0              | petroleum handling systems         | petroleum handling system | n/a                        | n/a | n/a                  |
| 37   | 0     | 2              | petroleum handling systems         | n/a                       | n/a                        | n/a | n/a                  |
| 44   | 0     | 7              | petroleum handling systems         | road operations           | misc 2                     | n/a | n/a                  |

**Table C 6: Site Characteristics**

| Site | Min Depth to GW (m) | pH          |             | Electrical Conductivity (EC) |       |       |       | SAR  |
|------|---------------------|-------------|-------------|------------------------------|-------|-------|-------|------|
|      |                     | Water       | Soil        | Soil                         | units | Water | units | Soil |
| 1    | 2.68                |             |             |                              |       |       |       |      |
| 6    | 1.418               |             |             |                              |       |       |       |      |
| 7    | 2.22                | 7.2 - 8.5   |             |                              |       | 3060  | uS/cm |      |
| 9    | 2.91                |             |             |                              |       |       |       |      |
| 10   | 4.5                 |             |             |                              |       |       |       |      |
| 11   | 5.7                 |             |             |                              |       |       |       |      |
| 13   | 3.81                | 6.89 - 7.87 |             |                              |       | 473   | uS/cm |      |
| 15   | 5.49                | 7.51 - 7.85 |             |                              |       | 582   | uS/cm |      |
| 16   | 5.65                | 7.25 - 7.7  |             |                              |       | 689   | uS/cm |      |
| 17   | 5.37                | 7.21 - 7.7  |             |                              |       | 710   | uS/cm |      |
| 18   | 3.15                |             |             |                              |       |       |       |      |
| 19   | 5                   |             |             |                              |       |       |       |      |
| 20   | 5                   |             | 8 - 8.4     | 78.6                         | mS/cm |       |       | 243  |
| 21   | 1.65                |             |             |                              |       |       |       |      |
| 22   | 1.24                | 5.13 - 9.2  |             |                              |       | 180   | uS/cm |      |
| 23   | 4                   | 7.12 - 8.34 |             |                              |       | 490   | uS/cm |      |
| 27   | 0.93                |             |             |                              |       |       |       |      |
| 31   | 2.82                | 6.5 - 7.6   |             |                              |       | 16300 | uS/cm |      |
| 37   | 1.984               |             |             |                              |       |       |       |      |
| 44   | 4.4                 | 7.1 - 7.6   | 8.96 - 9.47 |                              |       | 18080 | uS/cm |      |

**Table C 7: Soil Test Data - Exceedances (Part 1)**

| Site                             |                 | 1                                       | 6  | 7                                       | 9                                       | 10                                      | 11             | 13                 | 15                 | 16            | 17            |
|----------------------------------|-----------------|---|--|---|---|---|----------------|--------------------|--------------------|---------------|---------------|
| Report Date                      |                 | 05 Jun 1997                             | 14 Feb 1996                                  | 01 Dec 2004                             | 18 Nov 1997                             | 18 Oct 1999                             | 20 Mar 2002    | 30 Apr 2004        | 30 Apr 2004        | 30 Apr 2004   | 30 Apr 2004   |
| AENV Generic Property Use        |                 | C;C;C;C;RP                              | C;RP;RP;C;RP                                 | C;C;I;RP;RP                             | C;A;A;RP;A                              | C;RP;C;RP;RP                            | RP;RP;RP;RP;RP | RP;RP;RP;RP;R<br>P | RP;RP;RP;RP;R<br>P | RP;RP;RP;I;RP | RP;RP;RP;I;I  |
| EXCEEDANCE                       | Reported        | Yes                                     | Yes  | Yes                                     | Yes                                     | Yes                                     | Yes            | Yes                | No                 | Yes           | No            |
|                                  | Identified      | Yes                                     | Yes  | Yes                                     | Yes                                     | Yes                                     | Yes            | Yes                | Yes                | Yes           | Yes           |
| Soil Type                        |                 | Coarse                                  | Fine   | Coarse                                  | Fine                                    | Coarse                                  | Fine           | Coarse             | Coarse             | Coarse        | Coarse        |
| TOTAL HYDROCARBONS & BTEX - SOIL | F1(C6-C10)      |   |  | 0; 0; 0; 0; 0                           |   |   |                |                    |                    |               |               |
|                                  | F1-BTEX         |   |  | 0; 12; 12; 12; 12                       |   |   |                |                    |                    |               |               |
|                                  | F2(C10-C16)     |   |  | 0; 0; 0; 0; 0                           |   |   |                |                    |                    |               | 0; 0; 0; 0; 0 |
|                                  | F3(C16-C34)     |   |  | 0; 0; 0; 0; 0                           |   |   |                | 0; 0; 0; 0; 0      |                    |               | 0; 0; 0; 0; 0 |
|                                  | F4(C34-C50)     |   |  | 0; 0; 0; 0; 0                           |   |   |                |                    |                    |               | 0; 0; 0; 0; 0 |
|                                  | Benzene         | 3.462; 3.462;<br>3.462; 3.462;<br>3.467 | 73.754; 73.754;<br>73.754; 73.754;<br>73.754 | 1.422; 1.422;<br>1.422; 1.427;<br>1.427 | 0.714; 0.714;<br>0.714; 0.714;<br>0.714 | 9.022; 9.027;<br>9.022; 9.027;<br>9.027 | 0; 0; 0; 0; 0  |                    |                    |               |               |
|                                  | Toluene         | 1.53; 1.53; 1.53;<br>1.53; 1.53         | 54.58; 54.58;<br>54.58; 54.58;<br>54.58      | 0; 0; 0; 0; 0                           | 0.39; 0.39; 0.39;<br>0.39; 0.39         | 61.11; 61.11;<br>61.11; 61.11;<br>61.11 | 0; 0; 0; 0; 0  |                    |                    |               |               |
|                                  | Ethyl Benzene   | 1.3; 1.3; 1.3; 1.3;<br>1.3              | 74.29; 74.29;<br>74.29; 74.29;<br>74.29      | 0; 0; 0; 0; 0                           | 0.2; 0.2; 0.2; 0.2;<br>0.2              | 16.29; 16.29;<br>16.29; 16.29;<br>16.29 | 0; 0; 0; 0; 0  |                    |                    |               |               |
|                                  | Xylenes (Mixed) |   | 211; 211; 211;<br>211; 211                   | 0; 0; 0; 0; 0                           |   |   |                |                    |                    |               |               |

**Table C 7: Soil Test Data - Exceedances (Part 1)**

| Site                      |   | 1                            | 6 | 7 | 9                            | 10                           | 11                                  | 13 | 15 | 16 | 17 |
|---------------------------|---|------------------------------|---|---|------------------------------|------------------------------|-------------------------------------|----|----|----|----|
| VOLATILE COMPOUNDS - SOIL | mp-Xylene                                 | 0; 3.88; 3.88;<br>3.88; 3.88 |   |   | 0; 3.78; 3.78;<br>3.78; 3.78 | 0; 68.6; 68.6;<br>68.6; 68.6 | 0; 0.032;<br>0.032; 0.032;<br>0.032 |    |    |    |    |
|                           | O-Xylene                                  | 0; 0.81; 0.81;<br>0.81; 0.81 |   |   | 0; 0.76; 0.76;<br>0.76; 0.76 | 0; 27.4; 27.4;<br>27.4; 27.4 | 0; 0.03; 0.03;<br>0.03; 0.03        |    |    |    |    |
|                           | 1,1-Dichloroethane                        |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 1,2-Dibromoethane<br>(ethylene dibromide) |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 1,2-Dichloropropane                       |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 1,3-Dichlorobenzene                       |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 1,1,2-Trichloroethane                     |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 1,1,1,2-Tetrachloroethane                 |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 1,1,2,2-Tetrachloroethane                 |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 2-Butanone(MEK)                           |                              |   |   |                              |                              | 0; 0.063; 0.063;<br>0.063; 0.063    |    |    |    |    |
|                           | 2-Hexanone                                |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | 4-Methyl-2-Pentanone(MIBK)                |                              |   |   |                              |                              |                                     |    |    |    |    |
|                           | Acetone                                   |                              |   |   |                              |                              | 0; 0.586; 0.586;<br>0.586; 0.586    |    |    |    |    |
|                           | Bromodichloromethane                      |                              |   |   |                              |                              |                                     |    |    |    |    |

**Table C 7: Soil Test Data - Exceedances (Part 1)**

| Site                      |   | 1 | 6 | 7 | 9 | 10 | 11                              | 13 | 15 | 16 | 17 |
|---------------------------|---|---|---|---|---|----|---------------------------------|----|----|----|----|
| VOLATILE COMPOUNDS - SOIL | Bromoform                               |   |   |   |   |    |                                 |    |    |    |    |
|                           | Bromomethane                            |   |   |   |   |    |                                 |    |    |    |    |
|                           | Carbon Tetrachloride                    |   |   |   |   |    |                                 |    |    |    |    |
|                           | Chlorobenzene                           |   |   |   |   |    |                                 |    |    |    |    |
|                           | Chloroethane                            |   |   |   |   |    |                                 |    |    |    |    |
|                           | Chloroform                              |   |   |   |   |    |                                 |    |    |    |    |
|                           | Chloromethane                           |   |   |   |   |    |                                 |    |    |    |    |
|                           | cis-1,2-Dichloroethene                  |   |   |   |   |    |                                 |    |    |    |    |
|                           | cis-1,3-Dichloropropene                 |   |   |   |   |    |                                 |    |    |    |    |
|                           | Dibromochloromethane                    |   |   |   |   |    |                                 |    |    |    |    |
|                           | Dichloromethane<br>(Methylene Chloride) |   |   |   |   |    |                                 |    |    |    |    |
|                           | Methyl-t-Butyl Ether<br>(MTBE)          |   |   |   |   |    |                                 |    |    |    |    |
|                           | Tetrachloroethene (PCE)                 |   |   |   |   |    | 0.21; 0.21; 0.21;<br>0.21; 0.21 |    |    |    |    |
|                           | trans-1,2-Dichloroethene                |   |   |   |   |    |                                 |    |    |    |    |

**Table C 7: Soil Test Data - Exceedances (Part 1)**

| Site  |                           | 1 | 6 | 7 | 9 | 10 | 11 | 13 | 15 | 16 | 17 |
|---|---------------------------|---|---|---|---|----|----|----|----|----|----|
|   | trans-1,3-Dichloropropene |   |   |   |   |    |    |    |    |    |    |
|   | Trichlorofluoromethane    |   |   |   |   |    |    |    |    |    |    |
|   | Vinyl Chloride            |   |   |   |   |    |    |    |    |    |    |
| POLYCYCLIC AROMATIC HYDROCARBONS (PAH's) - SOIL | Anthracene                |   |   |   |   |    |    |    |    |    |    |
|   | Benz(a)anthracene         |   |   |   |   |    |    |    |    |    |    |
|   | Benzo(b)fluoranthene      |   |   |   |   |    |    |    |    |    |    |
|   | Benzo(k)fluoranthene      |   |   |   |   |    |    |    |    |    |    |
|   | Benzo(g,h,i)perylene      |   |   |   |   |    |    |    |    |    |    |
|   | Chrysene                  |   |   |   |   |    |    |    |    |    |    |
|   | Fluoranthene              |   |   |   |   |    |    |    |    |    |    |
|   | Indeno (1,2,3-cd) pyrene  |   |   |   |   |    |    |    |    |    |    |
|   | 2-Methylnaphthalene       |   |   |   |   |    |    |    |    |    |    |
|   | Naphthalene               |   |   |   |   |    |    |    |    |    |    |
|   | Phenanthrene              |   |   |   |   |    |    |    |    |    |    |

**Table C 7: Soil Test Data - Exceedances (Part 1)**

| Site                     |                 | 1             | 6             | 7             | 9             | 10 | 11 | 13                                      | 15                                    | 16                                  | 17                                  |
|--------------------------|-----------------|---------------|---------------|---------------|---------------|----|----|---|---------------------------------------|-------------------------------------|-------------------------------------|
| METALS & ELEMENTS - SOIL | Pyrene          |               |               |               |               |    |    | 0.19; 0.19; 0.19;<br>0.19; 0.19         |                                       |                                     |                                     |
|                          | Aluminum (Al)   |               |               |               |               |    |    | 0; 13700; 13700;<br>13700; 13700        | 0; 12000; 12000;<br>12000; 12000      | 0; 20600;<br>20600; 20600;<br>20600 | 0; 12700;<br>12700; 12700;<br>12700 |
|                          | Boron (B)       |               |               |               |               |    |    |   |                                       |                                     |                                     |
|                          | Calcium (Ca)    |               |               |               |               |    |    | 0; 142000;<br>142000; 142000;<br>142000 |                                       |                                     |                                     |
|                          | Chromium (Cr)   |               |               |               |               |    |    | 0; 14; 14; 14; 14                       | 0; 15; 15; 15; 15                     | 0; 96; 96; 96; 96                   | 0; 19.3; 19.3;<br>19.3; 19.3        |
|                          | Copper (Cu)     |               |               |               |               |    |    | 0; 0; 0; 0; 0                           | 0; 0; 0; 0; 0                         | 198; 198; 198;<br>170; 198          | 63; 63; 63; 35;<br>35               |
|                          | Iron (Fe)       |               |               |               |               |    |    | 0; 14900; 14900;<br>14900; 14900        | 0; 13200; 13200;<br>13200; 13200      | 0; 29100; 29100;<br>29100; 29100    | 0; 13300; 13300;<br>13300; 13300    |
|                          | Lead (Pb)       | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 |    |    | 0; 0; 0; 0; 0                           | 13060;13060;<br>13060;13060;<br>13060 | 717; 717; 717;<br>257; 717          | 78; 78; 78; 0; 0                    |
|                          | Lithium (Li)    |               |               |               |               |    |    | 0; 9.8; 9.8; 9.8;<br>9.8                |                                       |                                     |                                     |
|                          | Magnesium (Mg)  |               |               |               |               |    |    | 0; 30800; 30800;<br>30800; 30800        |                                       |                                     |                                     |
|                          | Manganese (Mn)  |               |               |               |               |    |    | 0;378;378;378;<br>378                   | 0; 481; 481; 481;<br>481              | 0; 645; 645; 645;<br>645            | 0; 355; 355; 355;<br>355            |
|                          | Molybdenum (Mo) |               |               |               |               |    |    |   |                                       | 2; 2; 2; 0; 2                       | 0; 0; 0; 0; 0                       |
|                          | Nickel (Ni)     |               |               |               |               |    |    | 0; 0; 0; 0; 0                           | 0; 0; 0; 0; 0                         | 0; 0; 0; 0; 0                       | 0; 0; 0; 0; 0                       |
|                          | Phosphorus (P)  |               |               |               |               |    |    | 0; 1040; 1040;<br>1040; 1040            | 0; 980; 980; 980;<br>980              | 0; 2750; 2750;<br>2750; 2750        | 0; 816; 816; 816;<br>816            |
|                          | Potassium (K)   |               |               |               |               |    |    | 0; 1230; 1230;<br>1230; 1230            |                                       |                                     |                                     |



**Table C 7: Soil Test Data - Exceedances (Part 1)**

| Site                     |                | 1 | 6 | 7 | 9 | 10 | 11 | 13                         | 15                       | 16                       | 17                       |
|--------------------------|----------------|---|---|---|---|----|----|----------------------------|--------------------------|--------------------------|--------------------------|
| METALS & ELEMENTS - SOIL | Selenium (Se)  |   |   |   |   |    |    | 0.1; 0.1; 0.1; 0.1;<br>0.1 | 0; 0; 0; 0; 0            | 0; 0; 0; 0; 0            | 0; 0; 0; 0; 0            |
|                          | Sodium (Na)    |   |   |   |   |    |    | 0; 184; 184; 184;<br>184   |                          |                          |                          |
|                          | Strontium (Sr) |   |   |   |   |    |    | 0; 124; 124; 124;<br>124   | 0; 50; 50; 50; 50        | 0; 83; 83; 83; 83        | 0; 110; 110; 110;<br>110 |
|                          | Sulphur (S)    |   |   |   |   |    |    | 10; 10; 10; 10;<br>10      |                          |                          |                          |
|                          | Tellurium (Te) |   |   |   |   |    |    | 0; 0; 0; 0; 0              |                          |                          |                          |
|                          | Thallium (Tl)  |   |   |   |   |    |    |                            |                          |                          |                          |
|                          | Tin (Sn)       |   |   |   |   |    |    | 0; 0; 0; 0; 0              |                          |                          |                          |
|                          | Titanium (Ti)  |   |   |   |   |    |    | 0; 144; 144; 144;<br>144   | 0; 159; 159; 159;<br>159 | 0; 369; 369; 369;<br>369 | 0; 125; 125; 125;<br>125 |

**Table C 8: Soil Test Data - Exceedances (Part 2)**

| Site                             |                 | 18                                      | 19            | 20            | 21                                       | 22   | 23                                      | 27          | 31            | 37   | 44                              |
|----------------------------------|-----------------|---|---------------|---------------|--|--|---|-------------|---------------|--|---------------------------------|
| Report Date                      |                 | 08 Feb 1995                             | 06 Apr 2005   | 06 Apr 2005   | 24 Jun 1997                              | 05 Aug 2004                                  | 01 Sep 2005                             | 11 Jan 2002 | 01 Feb 2006   | 12 Feb 1997                                  | 01 Feb 2000                     |
| AENV Generic Property Use        |                 | C;C;C;C;RP                              | C;C;C;C;C     | C;RP;RP; C;C  | C;C;C;RP;RP                              | I;RP;RP; RP;RP                               | RP;RP;RP;RP;C                           | A;A;A;A; RP | C;C;C;C;C     | C;C;RP;RP;RP                                 | I;I;I;I;RP                      |
| EXCEEDANCE                       | Reported        | Yes                                     | Yes           | Yes           | Yes                                      | Yes  | Yes                                     | No          | Yes           | Yes  | Yes                             |
|                                  | Identified      | Yes                                     | Yes           | Yes           | Yes                                      | Yes  | Yes                                     | Yes         | Yes           | Yes  | Yes                             |
| Soil Type                        |                 | Coarse                                  | Coarse        | Coarse        | Coarse                                   | Coarse                                       | Coarse                                  | Fine        | Fine          | Fine   | Coarse                          |
| TOTAL HYDROCARBONS & BTEX - SOIL | F1(C6-C10)      |   |               |               |  | 3630; 3876;<br>3876; 3876;<br>3876           | 0; 0; 0; 0; 0                           |             |               |  |                                 |
|                                  | F1-BTEX         |   |               |               |  |  |   |             |               |  |                                 |
|                                  | F2(C10-C16)     |   |               |               |  | 16740; 16870;<br>16870; 16870;<br>16870      | 0; 0; 0; 0; 0                           |             |               |  |                                 |
|                                  | F3(C16-C34)     |   | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 |  | 30300; 31700;<br>31700; 31700;<br>31700      | 2310; 2310;<br>2310; 2310;<br>910       |             | 0; 0; 0; 0; 0 |  |                                 |
|                                  | F4(C34-C50)     |   | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 |  | 4800; 5300;<br>5300; 5300;<br>5300           | 23900; 23900;<br>23900; 23900;<br>23400 |             | 0; 0; 0; 0; 0 |  |                                 |
|                                  | Benzene         | 5.422; 5.422;<br>5.422; 5.422;<br>5.427 |               |               | 6.192; 6.192;<br>6.192; 6.197;<br>6.197; | 20.922; 20.927;<br>20.927; 20.927;<br>20.927 | 0; 0; 0; 0; 0                           |             |               | 10.354; 10.354;<br>10.354; 10.354;<br>10.354 |                                 |
|                                  | Toluene         | 28.51; 28.51;<br>28.51; 28.51;<br>28.51 | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 | 11.41; 11.41;<br>11.41; 11.41;<br>11.41  | 329.51; 329.51;<br>329.51; 329.51;<br>329.51 | 0; 0; 0; 0; 0                           |             |               | 25.58; 25.58;<br>25.58; 25.58;<br>25.58      |                                 |
|                                  | Ethyl Benzene   | 4.59; 4.59; 4.59;<br>4.59; 4.59         |               |               | 26.59; 26.59;<br>26.59; 26.59;<br>26.59  | 139.79; 139.79;<br>139.79; 139.79;<br>139.79 | 0; 0; 0; 0; 0                           |             |               | 19.39; 19.39;<br>19.39; 19.39;<br>19.39      | 0.79; 0.79; 0.79;<br>0.79; 0.79 |
|                                  | Xylenes (Mixed) | 8; 8; 8; 8; 24                          |               | 0; 0; 0; 0; 0 | 20.8; 20.8; 20.8;<br>36.8; 36.8          | 1072; 1088;<br>1088; 1088;<br>1088           | 0; 0; 0; 0; 0                           |             |               | 63.6; 63.6; 63.6;<br>63.6; 63.6              | 0; 0; 0; 0; 0                   |

**Table C 8: Soil Test Data - Exceedances (Part 2)**

| Site                      |   | 18 | 19 | 20                               | 21 | 22                       | 23                               | 27 | 31 | 37 | 44 |
|---------------------------|---|----|----|----------------------------------|----|--------------------------|----------------------------------|----|----|----|----|
| VOLATILE COMPOUNDS - SOIL | mp-Xylene                                 |    |    |                                  |    |                          |                                  |    |    |    |    |
|                           | O-Xylene                                  |    |    |                                  |    |                          |                                  |    |    |    |    |
|                           | 1,1-Dichloroethane                        |    |    |                                  |    |                          | 0; 0.002; 0.002;<br>0.002; 0.002 |    |    |    |    |
|                           | 1,2-Dibromoethane<br>(ethylene dibromide) |    |    |                                  |    |                          | 0; 0.002; 0.002;<br>0.002; 0.002 |    |    |    |    |
|                           | 1,2-Dichloropropane                       |    |    |                                  |    |                          | 0; 0.002; 0.002;<br>0.002; 0.002 |    |    |    |    |
|                           | 1,3-Dichlorobenzene                       |    |    |                                  |    |                          | 0; 0.002; 0.002;<br>0.002; 0.002 |    |    |    |    |
|                           | 1,1,2-Trichloroethane                     |    |    |                                  |    | 0; 2.9; 2.9; 2.9;<br>2.9 | 0; 0.002; 0.002;<br>0.002; 0.002 |    |    |    |    |
|                           | 1,1,1,2-Tetrachloroethane                 |    |    |                                  |    |                          | 0; 0.002; 0.002;<br>0.002; 0.002 |    |    |    |    |
|                           | 1,1,2,2-Tetrachloroethane                 |    |    |                                  |    |                          | 0; 0.002; 0.002;<br>0.002; 0.002 |    |    |    |    |
|                           | 2-Butanone(MEK)                           |    |    |                                  |    |                          | 0; 0.025; 0.025;<br>0.025; 0.025 |    |    |    |    |
|                           | 2-Hexanone                                |    |    |                                  |    |                          | 0; 0.025; 0.025;<br>0.025; 0.025 |    |    |    |    |
|                           | 4-Methyl-2-Pentanone(MIBK)                |    |    |                                  |    |                          | 0; 0.025; 0.025;<br>0.025; 0.025 |    |    |    |    |
|                           | Acetone                                   |    |    | 0; 0.173; 0.173;<br>0.173; 0.173 |    |                          | 0; 0.1; 0.1; 0.1;<br>0.1         |    |    |    |    |

**Table C 8: Soil Test Data - Exceedances (Part 2)**

| Site                      |   | 18 | 19            | 20            | 21 | 22                                      | 23   | 27 | 31 | 37 | 44 |
|---------------------------|---|----|---------------|---------------|----|---|--|----|----|----|----|
| VOLATILE COMPOUNDS - SOIL | Bromodichloromethane                    |    |               |               |    |   | 0; 0.002; 0.002;<br>0.002; 0.002               |    |    |    |    |
|                           | Bromoform                               |    |               |               |    |   | 0; 0.002; 0.002;<br>0.002; 0.002               |    |    |    |    |
|                           | Bromomethane                            |    |               |               |    |   | 0; 0.003; 0.003;<br>0.003; 0.003               |    |    |    |    |
|                           | Carbon Tetrachloride                    |    |               |               |    |   | 0.00144;<br>0.00144;<br>0.00144;<br>0.00144; 0 |    |    |    |    |
|                           | Chlorobenzene                           |    |               |               |    | 0; 0.122; 0.122;<br>0.122; 0.122        | 0; 0; 0; 0; 0                                  |    |    |    |    |
|                           | Chloroethane                            |    |               |               |    |   | 0; 0.005; 0.005;<br>0.005; 0.005               |    |    |    |    |
|                           | Chloroform                              |    |               |               |    |   | 0.001; 0.001;<br>0.001; 0.001; 0               |    |    |    |    |
|                           | Chloromethane                           |    |               |               |    |   | 0; 0.005; 0.005;<br>0.005; 0.005               |    |    |    |    |
|                           | cis-1,2-Dichloroethene                  |    |               |               |    |   | 0; 0.002; 0.002;<br>0.002; 0.002               |    |    |    |    |
|                           | cis-1,3-Dichloropropene                 |    |               |               |    |   | 0; 0.002; 0.002;<br>0.002; 0.002               |    |    |    |    |
|                           | Dibromochloromethane                    |    |               |               |    |   | 0; 0; 0; 0; 0                                  |    |    |    |    |
|                           | Dichloromethane<br>(Methylene Chloride) |    | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 |    | 0.175; 0.175;<br>0.175; 0.175;<br>0.175 | 0; 0; 0; 0; 0                                  |    |    |    |    |
|                           | Methyl-t-Butyl Ether<br>(MTBE)          |    |               |               |    |   | 0; 0; 0; 0; 0                                  |    |    |    |    |
|                           | Tetrachloroethene (PCE)                 |    | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0 |    |   | 0; 0; 0; 0; 0                                  |    |    |    |    |

**Table C 8: Soil Test Data - Exceedances (Part 2)**

| Site  |                           | 18 | 19 | 20 | 21 | 22                           | 23   | 27 | 31 | 37 | 44 |
|---|---------------------------|----|----|----|----|------------------------------|--|----|----|----|----|
|   | trans-1,2-Dichloroethene  |    |    |    |    |                              | 0; 0.002; 0.002;<br>0.002; 0.002               |    |    |    |    |
|   | trans-1,3-Dichloropropene |    |    |    |    |                              | 0; 0.002; 0.002 ;<br>0.002; 0.002              |    |    |    |    |
|   | Trichlorofluoromethane    |    |    |    |    | 0; 0.28; 0.28;<br>0.28; 0.28 | 0; 0.005; 0.005;<br>0.005; 0.005               |    |    |    |    |
|   | Vinyl Chloride            |    |    |    |    |                              | 0.00166;<br>0.00166;<br>0.00166;<br>0.00166; 0 |    |    |    |    |
| POLYCYCLIC AROMATIC HYDROCARBONS (PAH's) - SOIL | Anthracene                |    |    |    |    |                              | 0.0444; 0.0444;<br>0.0444; 0.0444;<br>0.0444   |    |    |    |    |
|   | Benz(a)anthracene         |    |    |    |    |                              | 0.677; 0.677;<br>0.677; 0.677;<br>0.677        |    |    |    |    |
|   | Benzo(b)fluoranthene      |    |    |    |    |                              | 0; 1.4; 1.4; 1.4;<br>1.4                       |    |    |    |    |
|   | Benzo(k)fluoranthene      |    |    |    |    |                              | 0; 0.68; 0.68;<br>0.68; 0.68                   |    |    |    |    |
|   | Benzo(g,h,i)perylene      |    |    |    |    |                              | 0; 0.05; 0.05;<br>0.05; 0.05                   |    |    |    |    |
|   | Chrysene                  |    |    |    |    |                              | 0; 0.05; 0.05;<br>0.05; 0.05                   |    |    |    |    |
|   | Fluoranthene              |    |    |    |    |                              | 0.011; 0.011;<br>0.011; 0.011;<br>0.011        |    |    |    |    |
|   | Indeno(1,2,3-cd)pyrene    |    |    |    |    |                              | 0; 1.3; 1.3; 1.3;<br>1.3                       |    |    |    |    |
|   | 2-Methylnaphthalene       |    |    |    |    |                              | 0; 0.21; 0.21;<br>0.21; 0.21                   |    |    |    |    |
|   | Naphthalene               |    |    |    |    |                              | 1.182; 1.182;<br>1.182; 1.182;<br>1.182        |    |    |    |    |

**Table C 8: Soil Test Data - Exceedances (Part 2)**

| Site                     |                 | 18            | 19                               | 20                                      | 21            | 22                                      | 23                                      | 27                              | 31                               | 37 | 44                                      |
|--------------------------|-----------------|---------------|----------------------------------|---|---------------|---|---|---------------------------------|----------------------------------|----|---|
| METALS & ELEMENTS - SOIL | Phenanthrene    |               |                                  |   |               |   | 2.139; 2.139;<br>2.139; 2.139;<br>2.139 |                                 |                                  |    |   |
|                          | Pyrene          |               |                                  |   |               |   | 1.16; 1.16; 1.16;<br>1.16; 1.16         |                                 |                                  |    |   |
|                          | Aluminum (Al)   |               | 0;10100; 10100;<br>10100; 10100  | 0;10400; 10400;<br>10400; 10400         |               | 0;12400; 12400;<br>12400; 12400         | 0; 8190; 8190;<br>8190; 8190            | 0; 9000; 9000;<br>9000; 9000    |                                  |    | 0; 5930; 5930;<br>5930; 5930            |
|                          | Boron (B)       |               | 32.5; 32.5; 32.5;<br>32.5; 32.5  | 17.5; 17.5; 17.5;<br>17.5; 17.5         |               |   |   |                                 |                                  |    |   |
|                          | Calcium (Ca)    |               | 0; 88200; 88200;<br>88200;88200  | 0; 105000;<br>105000; 105000;<br>105000 |               | 0; 138000;<br>138000; 138000;<br>138000 | 0; 123000;<br>123000; 123000;<br>123000 |                                 |                                  |    | 0; 161000;<br>161000; 161000;<br>161000 |
|                          | Chromium (Cr)   |               | 0; 29.6; 29.6;<br>29.6; 29.6     | 0; 28.3; 28.3;<br>28.3; 28.3            |               | 0; 15.8; 15.8;<br>15.8; 15.8            | 0; 28.8; 28.8;<br>28.8; 28.8            | 0;16;16;16;16                   | 0; 115.3; 115.3;<br>115.3; 115.3 |    | 0; 57.2; 57.2;<br>57.2; 57.2            |
|                          | Copper (Cu)     |               | 0; 0; 0; 0; 0                    | 0; 0; 0; 0; 0                           |               | 767; 795; 795;<br>795; 795              | 53; 53; 53; 53;<br>25                   | 0; 0; 0; 0; 0                   | 0; 0; 0; 0; 0                    |    | 445; 445; 445;<br>445; 473              |
|                          | Iron (Fe)       |               | 0; 20600; 20600;<br>20600; 20600 | 0;14100; 14100;<br>14100; 14100         |               | 0;40300; 40300;<br>40300; 40300         | 0;16300; 16300;<br>16300; 16300         | 0;19200; 19200;<br>19200; 19200 |                                  |    | 0;125000;<br>125000; 125000;<br>125000  |
|                          | Lead (Pb)       | 0; 0; 0; 0; 0 | 0; 0; 0; 0; 0                    | 0; 0; 0; 0; 0                           | 0; 0; 0; 0; 0 | 0;391; 391; 391;<br>391                 | 313; 313; 313;<br>313; 193              | 0; 0; 0; 0; 0                   | 0; 0; 0; 0; 0                    |    | 1650; 1650;<br>1650; 1650;<br>2110      |
|                          | Lithium (Li)    |               | 0; 8.9; 8.9; 8.9;<br>8.9         | 0; 10.2; 10.2;<br>10.2; 10.2            |               | 0; 12; 12; 12; 12                       |   |                                 |                                  |    |   |
|                          | Magnesium (Mg)  |               | 0; 12200; 12200;<br>12200; 12200 | 0;24600; 24600;<br>24600; 24600         |               | 0; 25700; 25700;<br>25700; 25700        | 0;30900; 30900;<br>30900; 30900         |                                 |                                  |    | 0;26400; 26400;<br>26400; 26400         |
|                          | Manganese (Mn)  |               | 0; 416; 416; 416;<br>416         | 0; 374; 374; 374;<br>374                |               | 0; 492; 492; 492;<br>492                | 0; 356; 356; 356;<br>356                | 0; 338; 338; 338;<br>338        |                                  |    | 0; 762; 762; 762;<br>762                |
|                          | Molybdenum (Mo) |               | 0; 0; 0; 0; 0                    | 0; 0; 0; 0; 0                           |               | 0; 7.3; 7.3; 7.3;<br>7.3                | 10; 10; 10; 10; 0                       |                                 | 0; 0; 0; 0; 0                    |    | 0; 0; 0; 0; 0                           |
|                          | Nickel (Ni)     |               | 0; 0; 0; 0; 0                    | 0; 0; 0; 0; 0                           |               | 0; 0; 0; 0; 0                           | 0; 0; 0; 0; 0                           | 0; 0; 0; 0; 0                   | 0; 0; 0; 0; 0                    |    | 27; 27; 27; 27;<br>27                   |

**Table C 8: Soil Test Data - Exceedances (Part 2)**

| Site                     |                | 18 | 19                                 | 20                           | 21 | 22                                 | 23                           | 27                       | 31            | 37 | 44                                 |
|--------------------------|----------------|----|------------------------------------|------------------------------|----|------------------------------------|------------------------------|--------------------------|---------------|----|------------------------------------|
| METALS & ELEMENTS - SOIL | Phosphorus (P) |    | 0; 1650; 1650;<br>1650; 1650       | 0; 1210; 1210;<br>1210; 1210 |    | 0; 953; 953; 953;<br>953           | 0; 669; 669; 669;<br>669     | 0; 508; 508; 508;<br>508 |               |    | 0; 530; 530; 530;<br>530           |
|                          | Potassium (K)  |    | 0; 2580; 2580;<br>2580; 2580       | 0; 1600; 1600;<br>1600; 1600 |    | 0; 2680; 2680;<br>2680; 2680       | 0; 1640; 1640;<br>1640; 1640 |                          |               |    | 0; 8320; 8320;<br>8320; 8320       |
|                          | Selenium (Se)  |    |                                    |                              |    | 0; 0; 0; 0; 0                      |                              |                          | 0; 0; 0; 0; 0 |    |                                    |
|                          | Sodium (Na)    |    | 0; 783; 783; 783;<br>783           | 0; 8970; 8970;<br>8970; 8970 |    | 0; 400; 400; 400;<br>400           | 0; 178; 178; 178;<br>178     |                          |               |    | 0; 20000; 20000;<br>20000; 20000   |
|                          | Strontium (Sr) |    | 0; 92.6; 92.6;<br>92.6; 92.6       | 0; 144; 144; 144;<br>144     |    | 0; 159; 159; 159;<br>159           | 0; 93.5; 93.5;<br>93.5; 93.5 |                          |               |    | 0; 516; 516; 516;<br>516           |
|                          | Sulphur (S)    |    | 1110; 1110;<br>1110; 1110;<br>1110 | 50; 50; 50; 50;<br>50        |    | 6770; 6770;<br>6770; 6770;<br>6770 |                              |                          |               |    | 3000; 3000;<br>3000; 3000;<br>3000 |
|                          | Tellurium (Te) |    |                                    |                              |    |                                    |                              |                          |               |    |                                    |
|                          | Thallium (Tl)  |    | 0; 0; 0; 0; 0                      | 0; 0; 0; 0; 0                |    |                                    |                              |                          |               |    | 3; 3; 3; 3; 3                      |
|                          | Tin (Sn)       |    | 0; 0; 0; 0; 0                      | 0; 0; 0; 0; 0                |    | 0; 89.8; 89.8;<br>89.8; 89.8       | 0; 0; 0; 0; 0                |                          |               |    | 230; 230; 230;<br>230; 525         |
|                          | Titanium (Ti)  |    | 0; 111; 111; 111;<br>111           | 0; 122; 122; 122;<br>122     |    | 0; 64.3; 64.3;<br>64.3; 64.3       | 0; 37; 37; 37; 37            | 0; 59; 59; 59; 59        |               |    | 0; 138; 138; 138;<br>138           |

**Table C 9: Water Test Data - Exceedances (Part 1)**

| Site                                 |  | 1                          | 6            | 7                                    | 9                              | 10           | 11                                     | 13             | 15             | 16             | 17                 |
|--------------------------------------|--|----------------------------|--------------|--------------------------------------|--------------------------------|--------------|--|----------------|----------------|----------------|--------------------|
| Report Date                          |  | 05 Jun 1997                | 14 Feb 1996  | 01 Dec 2004                          | 18 Nov 1997                    | 18 Oct 1999  | 20 Mar 2002                            | 30 Apr 2004    | 30 Apr 2004    | 30 Apr 2004    | 30 Apr 2004        |
| AENV Generic Property Use            |  | C;C;C;C;RP                 | C;RP;RP;C;RP | C;C;I;RP;RP                          | C;A;A;RP;A                     | C;RP;C;RP;RP | RP;RP;RP;RP;RP                         | RP;RP;RP;RP;RP | RP;RP;RP;RP;RP | RP;RP;RP;I; RP | RP; RP; RP; I; I   |
| EXCEEDANCE                           | Reported                               | Yes                        | Yes          | Yes                                  | Yes                            | No           | Yes                                    | Yes            | No             | Yes            | No                 |
|                                      | Identified                             | Yes                        | Yes          | Yes                                  | Yes                            | N/A          | Yes                                    | Yes            | N/A            | N/A            | Yes                |
| Soil Type                            |  | Coarse                     | Fine         | Coarse                               | Fine                           | Coarse       | Fine                                   | Coarse         | Coarse         | Coarse         | Coarse             |
| HYDROCARBON FRACTIONS & BTEX - WATER | F2(C10-C16)                            |                            |              | 6.3; 7.4; 7.4; 7.4                   |                                |              |  |                |                |                | 1.3; 2.4; 2.4; 2.4 |
|                                      | F1-BTEX                                |                            |              | 5; 5; 5; 5; 5                        |                                |              |  |                |                |                |                    |
|                                      | Benzene                                | 14.995; 15; 15; 15; 15     |              | 0.0002;0.0052; 0.0052;0.0052; 0.0052 | 13.495; 13.5; 13.5; 13.5; 13.5 |              | 0; 0.0005; 0.0005; 0.0005; 0.0005      |                |                |                |                    |
|                                      | Toluene                                | 11.976; 12; 12;12; 12      |              | 0; 0.0036; 0.0036; 0.0036; 0.0036    | 3.366; 3.39; 3.39; 3.39; 3.39  |              | 0; 0.0004; 0.0004; 0.0004; 0.0004      |                |                |                |                    |
|                                      | Ethyl Benzene                          | 1.8976; 1.9; 1.9; 1.9; 1.9 |              | 0.3776; 0.38; 0.38; 0.38; 0.38       | 0.8776; 0.88; 0.88; 0.88; 0.88 |              | 0; 0.0007; 0.0007; 0.0007; 0.0007      |                |                |                |                    |
|                                      | Xylenes (Mixed)                        |                            |              | 0.65; 0.95; 0.95; 0.95; 0.95         |                                |              |  |                |                |                |                    |
|                                      | mp-Xylene                              | 8.7; 8.7; 8.7; 8.7; 8.7    |              |                                      | 3.22; 3.22; 3.22; 3.22; 3.22   |              | 0.0013; 0.0013; 0.0013; 0.0013; 0.0013 |                |                |                |                    |
|                                      | O-Xylene                               | 4.1; 4.1; 4.1; 4.1; 4.1    |              |                                      | 1.44; 1.44; 1.44; 1.44; 1.44   |              | 0.0006; 0.0006; 0.0006; 0.0006; 0.0006 |                |                |                |                    |
|                                      | F1(C6-C10)                             |                            |              | 4.1; 6.3; 6.3; 6.3; 6.3              |                                |              |  |                |                |                |                    |
|                                      | 1,2-Dibromoethane (ethylene dibromide) |                            |              |                                      |                                |              |  |                |                |                |                    |
|                                      | 1,2-Dichlorobenzene                    |                            |              |                                      |                                |              | 0.0001; 0.0008; 0.0008; 0.0008; 0.0008 |                |                |                |                    |
|                                      | 1,2-Dichloroethane                     |                            |              |                                      |                                |              |  |                |                |                |                    |
|                                      | 1,2-Dichloropropane                    |                            |              |                                      |                                |              |  |                |                |                |                    |
|                                      | 1,3-Dichlorobenzene                    |                            |              |                                      |                                |              |  |                |                |                |                    |
|                                      | 1,4-Dichlorobenzene                    |                            |              |                                      |                                |              |  |                |                |                |                    |



**Table C 9: Water Test Data - Exceedances (Part 1)**

| Site                       |   | 1 | 6 | 7 | 9 | 10 | 11   | 13   | 15 | 16 | 17 |
|----------------------------|---|---|---|---|---|----|--|--|----|----|----|
| VOLATILE COMPOUNDS - WATER | 1,1,1-Trichloroethane                   |   |   |   |   |    |  |  |    |    |    |
|                            | 1,1,2-Trichloroethane                   |   |   |   |   |    |  |  |    |    |    |
|                            | 1,1,1,2-Tetrachloroethane               |   |   |   |   |    |  |  |    |    |    |
|                            | 1,1,2,2-Tetrachloroethane               |   |   |   |   |    |  |  |    |    |    |
|                            | 2-Hexanone                              |   |   |   |   |    |  |  |    |    |    |
|                            | Acetone                                 |   |   |   |   |    |  |  |    |    |    |
|                            | Bromodichloromethane                    |   |   |   |   |    |  |  |    |    |    |
|                            | Bromoform                               |   |   |   |   |    |  |  |    |    |    |
|                            | Bromomethane                            |   |   |   |   |    |  |  |    |    |    |
|                            | Carbon Tetrachloride                    |   |   |   |   |    |  |  |    |    |    |
|                            | Chlorobenzene                           |   |   |   |   |    | 0; 0.0007;<br>0.0007; 0.0007;<br>0.0007      |  |    |    |    |
|                            | Chloroethane                            |   |   |   |   |    |  |  |    |    |    |
|                            | Chloroform                              |   |   |   |   |    | 0; 0.0005;<br>0.0005; 0.0005;<br>0.0005      | 0; 0.0014;<br>0.0014; 0.0014;<br>0.0014        |    |    |    |
|                            | Chloromethane                           |   |   |   |   |    |  |  |    |    |    |
|                            | cis-1,2-dichloroethene                  |   |   |   |   |    | 0.0031; 0.0031;<br>0.0031; 0.0031;<br>0.0031 |  |    |    |    |
|                            | cis-1,3-dichloropropene                 |   |   |   |   |    |  |  |    |    |    |
|                            | Dibromochloromethane                    |   |   |   |   |    |  |  |    |    |    |
|                            | Dichloromethane<br>(Methylene Chloride) |   |   |   |   |    |  |  |    |    |    |
|                            | Methyl Ethyl Ketone<br>(MEK)            |   |   |   |   |    |  |  |    |    |    |
|                            | Methyl IsoButyl Ketone<br>(MIBK)        |   |   |   |   |    |  |  |    |    |    |
|                            | Methyl-t-Butyl-Ether<br>(MTBE)          |   |   |   |   |    |  |  |    |    |    |
|                            | Naphthalene                             |   |   |   |   |    |  | 0; 0.00039;<br>0.00039;<br>0.00039;<br>0.00039 |    |    |    |
|                            | Styrene                                 |   |   |   |   |    |  |  |    |    |    |
|                            | Tetrachloroethene<br>(PCE)              |   |   |   |   |    | 0; 0.0007;<br>0.0007; 0.0007;<br>0.0007      |  |    |    |    |

**Table C 9: Water Test Data - Exceedances (Part 1)**

| Site  |                           | 1 | 6 | 7 | 9 | 10 | 11   | 13   | 15 | 16 | 17 |
|---|---------------------------|---|---|---|---|----|--|--|----|----|----|
| POLYCYCLIC AROMATIC COMPOUNDS (PAH's) - WATER | trans-1,2-Dichloroethene  |   |   |   |   |    | 0.0001;0.0001;<br>0.0001;0.0001;<br>0.0001 |  |    |    |    |
|   | trans-1,3-Dichloropropene |   |   |   |   |    |  |  |    |    |    |
|   | Trichloroethene (TCE)     |   |   |   |   |    |  |  |    |    |    |
|   | Trichlorofluoromethane    |   |   |   |   |    |  |  |    |    |    |
|   | Vinyl Chloride            |   |   |   |   |    |  |  |    |    |    |
|   | 1-Methylnaphthalene       |   |   |   |   |    |  |  |    |    |    |
|   | 2-Methylnaphthalene       |   |   |   |   |    |  |  |    |    |    |
|   | Acenaphthalene            |   |   |   |   |    |  |  |    |    |    |
|   | Acenaphthene              |   |   |   |   |    |  |  |    |    |    |
|   | Anthracene                |   |   |   |   |    |  |  |    |    |    |
|   | Benz(a)anthracene         |   |   |   |   |    |  |  |    |    |    |
|   | Benzo(b)fluoranthene      |   |   |   |   |    |  |  |    |    |    |
|   | Benzo(k)fluoranthene      |   |   |   |   |    |  |  |    |    |    |
|   | Benzo(g,h,i)perylene      |   |   |   |   |    |  |  |    |    |    |
|   | Benzo(a)pyrene            |   |   |   |   |    |  |  |    |    |    |
|   | Chrysene                  |   |   |   |   |    |  |  |    |    |    |
|   | Dibenz(a,h)anthracene     |   |   |   |   |    |  |  |    |    |    |
|   | Fluoranthene              |   |   |   |   |    |  |  |    |    |    |
|   | Fluorene                  |   |   |   |   |    |  |  |    |    |    |
|   | Indeno(1,2,3-cd)pyrene    |   |   |   |   |    |  |  |    |    |    |
|   | Phenanthrene              |   |   |   |   |    |  |  |    |    |    |
|   | Pyrene                    |   |   |   |   |    |  | 0.000145;<br>0.00017;<br>0.00017;<br>0.00017;<br>0.00017 |    |    |    |
|   | Aluminum (Al)             |   |   |   |   |    |  | 0; 0.016; 0.016;<br>0.016; 0.016                         |    |    |    |
|   | Antimony (Sb)             |   |   |   |   |    |  |  |    |    |    |
|   | Arsenic (As)              |   |   |   |   |    |  | 0; 0.003; 0.003;<br>0.003; 0.003                         |    |    |    |
|   | Barium (Ba)               |   |   |   |   |    |  | 0; 0.102; 0.102;<br>0.102; 0.102                         |    |    |    |
|   | Beryllium (Be)            |   |   |   |   |    |  |  |    |    |    |

**Table C 9: Water Test Data - Exceedances (Part 1)**

| Site                      |                        | 1      | 6  | 7 | 9 | 10 | 11 | 13   | 15 | 16 | 17 |
|---------------------------|------------------------|--------|--|---|---|----|----|--|----|----|----|
| METALS & ELEMENTS - WATER | <b>Bismuth (Bi)</b>    |        |  |   |   |    |    |  |    |    |    |
|                           | <b>Boron (B)</b>       |        |  |   |   |    |    |  |    |    |    |
|                           | <b>Cadmium (Cd)</b>    |        |  |   |   |    |    |  |    |    |    |
|                           | <b>Calcium (Ca)</b>    |        | 555; 555; 555;<br>555; 555                   |   |   |    |    | 445; 445; 445;<br>445; 445                     |    |    |    |
|                           | <b>Chromium (Cr)</b>   | 14.995 |  |   |   |    |    | 0.005; 0.005;<br>0.005; 0.005;<br>0.005        |    |    |    |
|                           | <b>Cobalt (Co)</b>     | 15     | 0.016; 0.016;<br>0.016; 0.016;<br>0.016      |   |   |    |    | 0.004; 0.004;<br>0.004; 0.004;<br>0.004        |    |    |    |
|                           | <b>Copper (Cu)</b>     | 15     | 0.0006; 0.0076;<br>0.0076; 0.0076;<br>0.0076 |   |   |    |    | 0.032; 0.039;<br>0.039; 0.039;<br>0.039        |    |    |    |
|                           | <b>Iron (Fe)</b>       | 15     | 0; 0.08; 0.08;<br>0.08; 0.08                 |   |   |    |    | 0.684; 0.984;<br>0.984; 0.984;<br>0.984        |    |    |    |
|                           | <b>Lead (Pb)</b>       | 15     |  |   |   |    |    | 0.000099;<br>0.0021; 0.0021;<br>0.0021; 0.0021 |    |    |    |
|                           | <b>Lithium (Li)</b>    |        |  |   |   |    |    | 0.213; 0.213;<br>0.213; 0.213;<br>0.213        |    |    |    |
|                           | <b>Magnesium (Mg)</b>  |        | 297; 297; 297;<br>297; 297                   |   |   |    |    | 766; 766; 766;<br>766; 766                     |    |    |    |
|                           | <b>Manganese (Mn)</b>  |        | 3.13; 3.18; 3.18;<br>3.18; 3.18              |   |   |    |    | 0.564; 0.614;<br>0.614; 0.614;<br>0.614        |    |    |    |
|                           | <b>Mercury (Hg)</b>    |        |  |   |   |    |    |  |    |    |    |
|                           | <b>Molybdenum (Mo)</b> |        | 0.002; 0.002;<br>0.002; 0.002;<br>0.002      |   |   |    |    | 0.008; 0.008;<br>0.008; 0.008;<br>0.008        |    |    |    |
|                           | <b>Nickel (Ni)</b>     |        | 0; 0.047; 0.047;<br>0.047; 0.047             |   |   |    |    | 0; 0.042; 0.042;<br>0.042; 0.042               |    |    |    |
|                           | <b>Phosphorus (P)</b>  |        |  |   |   |    |    |  |    |    |    |
|                           | <b>Potassium (K)</b>   |        | 13.8; 13.8; 13.8;<br>13.8; 13.8              |   |   |    |    | 51.9; 51.9; 51.9;<br>51.9; 51.9                |    |    |    |
|                           | <b>Selenium (Se)</b>   |        |  |   |   |    |    | 0.0168; 0.0178;<br>0.0178; 0.0178;<br>0.0178   |    |    |    |
|                           | <b>Silver (Ag)</b>     |        |  |   |   |    |    | 0.0001; 0.0002;<br>0.0002; 0.0002;<br>0.0002   |    |    |    |

**Table C 9: Water Test Data - Exceedances (Part 1)**

| Site                      |                | 1 | 6   | 7 | 9 | 10 | 11 | 13   | 15 | 16 | 17 |
|---------------------------|----------------|---|---|---|---|----|----|--|----|----|----|
| METALS & ELEMENTS - WATER | Sodium (Na)    |   | 124; 324; 324;<br>324; 324                              |   |   |    |    | 2940; 3140;<br>3140; 3140;<br>3140           |    |    |    |
|                           | Strontium (Sr) |   | 3.28; 3.28; 3.28;<br>3.28; 3.28                         |   |   |    |    |  |    |    |    |
|                           | Thallium (Tl)  |   | 0.00012;<br>0.00012;<br>0.00012;<br>0.00012;<br>0.00012 |   |   |    |    | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002 |    |    |    |
|                           | Tin (Sb)       |   |   |   |   |    |    |  |    |    |    |
|                           | Titanium (Ti)  |   | 0.006; 0.006;<br>0.006; 0.006;<br>0.006                 |   |   |    |    | 0.015; 0.015;<br>0.015; 0.015;<br>0.015      |    |    |    |
|                           | Uranium (U)    |   | 0; 0; 0; 0; 0   |   |   |    |    | 0; 0; 0; 0; 0                                |    |    |    |
|                           | Vanadium (V)   |   | 0.0008; 0.0008;<br>0.0008; 0.0008;<br>0.0008            |   |   |    |    | 0.002; 0.002;<br>0.002; 0.002;<br>0.002      |    |    |    |
|                           | Zinc (Zn)      |   |   |   |   |    |    | 0; 0; 0; 0; 0                                |    |    |    |

**Table C 10: Water Test Data - Exceedances (Part 2)**

| Site                                 |   | 18                            | 19          | 20          | 21                                       | 22   | 23   | 27          | 31          | 37                                      | 44                                      |
|--------------------------------------|---|-------------------------------|-------------|-------------|--|--|--|-------------|-------------|---|---|
| Report Date                          |   | 08 Feb 1995                   | 06 Apr 2005 | 06 Apr 2005 | 24 Jun 1997                              | 05 Aug 2004                                  | 01 Sep 2005                                  | 11 Jan 2002 | 01 Feb 2006 | 12 Feb 1997                             | 01 Feb 2000                             |
| AENV Generic Property Use            |   | C;C;C;C;RP                    | C;C;C;C;C   | C;RP;RP;C;C | C;C;C;RP;RP                              | I;RP;RP;RP;RP                                | RP;RP;RP;RP;C                                | A;A;A;A;RP  | C;C;C;C;C   | C;C;RP;RP; RP                           | I;I;I;I;RP                              |
| EXCEEDANCE                           | Reported                                  | Yes                           | No          | No          | Yes                                      | Yes  | Yes  | Yes         | Yes         | No                                      | Yes                                     |
|                                      | Identified                                | Yes                           | N/A         | Yes         | Yes                                      | Yes  | Yes  | Yes         | Yes         | Yes                                     | Yes                                     |
| Soil Type                            |   | Coarse                        | Coarse      | Coarse      | Coarse                                   | Coarse                                       | Coarse                                       | Fine        | Fine        | Fine                                    | Coarse                                  |
| HYDROCARBON FRACTIONS & BTEX - WATER | F2(C10-C16)                               |                               |             |             |  | 2.1; 3.2; 3.2; 3.2;<br>3.2                   | 1.36; 2.46; 2.46;<br>2.46; 2.46              |             |             |   |   |
|                                      | F1-BTEX                                   |                               |             |             |  |  |  |             |             |   |   |
|                                      | Benzene                                   | 7.495; 7.5; 7.5;<br>7.5; 7.5  |             |             | 15.295; 15.3;<br>15.3; 15.3; 15.3        | 0.167; 0.172;<br>0.172; 0.172;<br>0.172      | 0; 0.00035;<br>0.00035;<br>0.00035; 0.00035  |             |             | 22.995; 23; 23;<br>23; 23               | 0; 0.0011;<br>0.0011; 0.0011;<br>0.0011 |
|                                      | Toluene                                   | 18.976; 19; 19;<br>19; 19     |             |             | 1.016; 1.04; 1.04;<br>1.04; 1.04         | 0.0394; 0.0634;<br>0.0634; 0.0634;<br>0.0634 | 0; 0.0002;<br>0.0002; 0.0002;<br>0.0002      |             |             | 25.376; 25.4;<br>25.4; 25.4; 25.4       |   |
|                                      | Ethyl Benzene                             | 2.1976; 2.2; 2.2;<br>2.2; 2.2 |             |             | 0.3606; 0.363;<br>0.363; 0.363;<br>0.363 | 0.5936; 0.596;<br>0.596; 0.596;<br>0.596     | 0;0.0007; 0.0007;<br>0.0007; 0.0007          |             |             | 2.2376; 2.24;<br>2.24; 2.24; 2.24       |   |
|                                      | Xylenes (Mixed)                           | 18.7;19;19;19;19              |             |             | 1.7; 2; 2; 2; 2                          | 3.86; 4.16; 4.16;<br>4.16; 4.16              | 0; 0.0006;<br>0.0006; 0.0006;<br>0.0006      |             |             | 11.67; 11.97;<br>11.97; 11.97;<br>11.97 |   |
|                                      | mp-Xylene                                 |                               |             |             |  |  |  |             |             |   |   |
|                                      | O-Xylene                                  |                               |             |             |  |  |  |             |             |   |   |
|                                      | F1(C6-C10)                                |                               |             |             |  | 2.4; 4.6; 4.6; 4.6;<br>4.6                   |  |             |             |   |   |
|                                      | 1,2-Dibromoethane<br>(ethylene dibromide) |                               |             |             |  | 0.0011; 0.0011;<br>0.0011; 0.0011;<br>0.0011 | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002 |             |             |   |   |
|                                      | 1,2-Dichlorobenzene                       |                               |             |             |  |  | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001      |             |             |   |   |
|                                      | 1,2-Dichloroethane                        |                               |             |             |  | 0; 0.0011;<br>0.0011; 0.0011;<br>0.0011      | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001      |             |             |   |   |
|                                      | 1,2-Dichloropropane                       |                               |             |             |  | 0.0016; 0.0016;<br>0.0016; 0.0016;<br>0.0016 | 0.0001; 0.0001;<br>0.0001; 0.0001;<br>0.0001 |             |             |   |   |

**Table C 10: Water Test Data - Exceedances (Part 2)**

| Site                       |                           | 18 | 19 | 20 | 21 | 22   | 23   | 27 | 31 | 37 | 44 |
|----------------------------|---------------------------|----|----|----|----|--|--|----|----|----|----|
| VOLATILE COMPOUNDS - WATER | 1,3-Dichlorobenzene       |    |    |    |    |  | 0.0001; 0.0001;<br>0.0001; 0.0001;<br>0.0001 |    |    |    |    |
|                            | 1,4-Dichlorobenzene       |    |    |    |    |  | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001      |    |    |    |    |
|                            | 1,1,1-Trichloroethane     |    |    |    |    |  | 0; 0; 0; 0; 0                                |    |    |    |    |
|                            | 1,1,2-Trichloroethane     |    |    |    |    | 0.005; 0.005;<br>0.005; 0.005;<br>0.005      | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002 |    |    |    |    |
|                            | 1,1,1,2-Tetrachloroethane |    |    |    |    |  | 0.0001; 0.0001;<br>0.0001; 0.0001;<br>0.0001 |    |    |    |    |
|                            | 1,1,2,2-Tetrachloroethane |    |    |    |    |  | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002 |    |    |    |    |
|                            | 2-Hexanone                |    |    |    |    |  | 0.005; 0.005;<br>0.005; 0.005;<br>0.005      |    |    |    |    |
|                            | Acetone                   |    |    |    |    |  | 0.01; 0.01; 0.01;<br>0.01; 0.01              |    |    |    |    |
|                            | Bromodichloro methane     |    |    |    |    | 0.0033; 0.0033;<br>0.0033; 0.0033;<br>0.0033 | 0.0001; 0.0001;<br>0.0001; 0.0001;<br>0.0001 |    |    |    |    |
|                            | Bromoform                 |    |    |    |    |  | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002 |    |    |    |    |
|                            | Bromomethane              |    |    |    |    |  | 0.0005; 0.0005;<br>0.0005; 0.0005;<br>0.0005 |    |    |    |    |
|                            | Carbon Tetrachloride      |    |    |    |    |  | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001      |    |    |    |    |
|                            | Chlorobenzene             |    |    |    |    |  | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001      |    |    |    |    |
|                            | Chloroethane              |    |    |    |    |  | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002 |    |    |    |    |
|                            | Chloroform                |    |    |    |    | 0.0062; 0.008;<br>0.008; 0.008;<br>0.008     | 0; 0.0009; 0.0009;<br>0.0009; 0.0009         |    |    |    |    |
|                            | Chloromethane             |    |    |    |    | 0.0089; 0.0089;<br>0.0089; 0.0089;<br>0.0089 | 0.0005; 0.0005;<br>0.0005; 0.0005;<br>0.0005 |    |    |    |    |

**Table C 10: Water Test Data - Exceedances (Part 2)**

| Site                       |   | 18 | 19 | 20 | 21 | 22                                      | 23  | 27 | 31 | 37 | 44 |
|----------------------------|---|----|----|----|----|---|---|----|----|----|----|
| VOLATILE COMPOUNDS - WATER | cis-1,2-dichloroethene                  |    |    |    |    |   | 0.0001; 0.0001;<br>0.0001; 0.0001;<br>0.0001      |    |    |    |    |
|                            | cis-1,3-dichloropropene                 |    |    |    |    |   | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002      |    |    |    |    |
|                            | Dibromochloro<br>methane                |    |    |    |    | 0; 0.0007;<br>0.0007; 0.0007;<br>0.0007 | 0; 0.0002;<br>0.0002; 0.0002;<br>0.0002           |    |    |    |    |
|                            | Dichloromethane<br>(Methylene Chloride) |    |    |    |    | 0; 0.014; 0.014;<br>0.014; 0.014        | 0; 0.0005;<br>0.0005; 0.0005;<br>0.0005           |    |    |    |    |
|                            | Methyl Ethyl Ketone<br>(MEK)            |    |    |    |    |   | 0; 0; 0; 0; 0                                     |    |    |    |    |
|                            | Methyl IsoButyl Ketone<br>(MIBK)        |    |    |    |    |   | 0; 0; 0; 0; 0                                     |    |    |    |    |
|                            | Methyl-t-Butyl-Ether<br>(MTBE)          |    |    |    |    |   | 0; 0; 0; 0; 0                                     |    |    |    |    |
|                            | Naphthalene                             |    |    |    |    |   | 0; 0.0007;<br>0.0007; 0.0007;<br>0.0007           |    |    |    |    |
|                            | Styrene                                 |    |    |    |    | 0; 0.0007;<br>0.0007; 0.0007;<br>0.0007 | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001           |    |    |    |    |
|                            | Tetrachloroethene<br>(PCE)              |    |    |    |    |   | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001           |    |    |    |    |
|                            | trans-1,2-<br>Dichloroethene            |    |    |    |    |   | 0.0001; 0.0001;<br>0.0001; 0.0001;<br>0.0001      |    |    |    |    |
|                            | trans-1,3-<br>Dichloropropene           |    |    |    |    |   | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002      |    |    |    |    |
|                            | Trichloroethene (TCE)                   |    |    |    |    |   | 0; 0.0001;<br>0.0001; 0.0001;<br>0.0001           |    |    |    |    |
|                            | Trichlorofluoro<br>methane              |    |    |    |    | 0.001; 0.001;<br>0.001; 0.001;<br>0.001 | 0.0002; 0.0002;<br>0.0002; 0.0002;<br>0.0002      |    |    |    |    |
|                            | Vinyl Chloride                          |    |    |    |    |   | 0; 0.0002;<br>0.0002; 0.0002;<br>0.0002           |    |    |    |    |
|                            | 1-Methylnaphthalene                     |    |    |    |    |   | 0; 0; 0; 0; 0                                     |    |    |    |    |
|                            | 2-Methylnaphthalene                     |    |    |    |    |   | 0.00005; 0.00005;<br>0.00005; 0.00005;<br>0.00005 |    |    |    |    |

**Table C 10: Water Test Data - Exceedances (Part 2)**

| Site  |                       | 18 | 19 | 20 | 21 | 22 | 23   | 27 | 31 | 37 | 44 |
|---|-----------------------|----|----|----|----|----|--|----|----|----|----|
| POLYCYCLIC AROMATIC COMPOUNDS (PAH's) - WATER | Acenaphthalene        |    |    |    |    |    | 0.00005;0.00005;<br>0.00005;0.00005;<br>0.00005              |    |    |    |    |
|   | Acenaphthene          |    |    |    |    |    | 0; 0.00101;<br>0.00101;<br>0.00101; 0.00101                  |    |    |    |    |
|   | Anthracene            |    |    |    |    |    | 0; 0.00001;<br>0.00001;<br>0.00001; 0.00001                  |    |    |    |    |
|   | Benz(a)anthracene     |    |    |    |    |    | 0.000007;<br>0.000025;<br>0.000025;<br>0.000025;<br>0.000025 |    |    |    |    |
|   | Benzo(b)fluoranthene  |    |    |    |    |    | 0.000034;<br>0.000034;<br>0.000034;<br>0.000034;<br>0.000034 |    |    |    |    |
|   | Benzo(k)fluoranthene  |    |    |    |    |    | 0; 0.000029;<br>0.000029;<br>0.000029;<br>0.000029           |    |    |    |    |
|   | Benzo(g,h,i)perylene  |    |    |    |    |    | 0; 0.000017;<br>0.000017;<br>0.000017;<br>0.000017           |    |    |    |    |
|   | Benzo(a)pyrene        |    |    |    |    |    | 0; 0.000011;<br>0.000011;<br>0.000011;<br>0.000011           |    |    |    |    |
|   | Chrysene              |    |    |    |    |    | 0; 0.000037;<br>0.000037;<br>0.000037;<br>0.000037           |    |    |    |    |
|   | Dibenz(a,h)anthracene |    |    |    |    |    | 0; 0.000011;<br>0.000011;<br>0.000011;<br>0.000011           |    |    |    |    |
|   | Fluoranthene          |    |    |    |    |    | 0; 0.000023;<br>0.000023;<br>0.000023;<br>0.000023           |    |    |    |    |
|   | Fluorene              |    |    |    |    |    | 0.00111;<br>0.00411;<br>0.00411;<br>0.00411; 0.00411         |    |    |    |    |



**Table C 10: Water Test Data - Exceedances (Part 2)**

| Site                      |                         | 18 | 19 | 20                                      | 21 | 22   | 23   | 27   | 31  | 37 | 44   |
|---------------------------|-------------------------|----|----|---|----|--|--|--|---|----|--|
|                           | Indeno(1,2,3-cd) pyrene |    |    |   |    |  | 0; 0.00002;<br>0.00002;<br>0.00002; 0.00002                  |  |   |    |  |
|                           | Phenanthrene            |    |    |   |    |  | 0.000302;<br>0.000702;<br>0.000702;<br>0.000702;<br>0.000702 |  |   |    |  |
|                           | Pyrene                  |    |    |   |    |  | 0.00018;<br>0.000205;<br>0.000205;<br>0.000205;<br>0.000205  |  |   |    |  |
| METALS & ELEMENTS - WATER | Aluminum (Al)           |    |    |   |    | 0.047; 0.147;<br>0.147; 0.147;<br>0.147                      | 0; 0.009; 0.009;<br>0.009; 0.009                             | 0; 0.006; 0.006;<br>0.006; 0.006               | 0.41; 0.51; 0.51;<br>0.51; 0.51               |    | 491.9; 492; 492;<br>492; 492               |
|                           | Antimony (Sb)           |    |    |   |    |  | 0; 0.0005;<br>0.0005; 0.0005;<br>0.0005                      |  | 0.003; 0.009;<br>0.009; 0.009;<br>0.009       |    |  |
|                           | Arsenic (As)            |    |    |   |    | 0.008; 0.013;<br>0.013; 0.013;<br>0.013                      | 0; 0.002; 0.002;<br>0.002; 0.002                             |  | 0; 0.0033;<br>0.0033; 0.0033;<br>0.0033       |    |  |
|                           | Barium (Ba)             |    |    |   |    | 0; 0.27; 0.27;<br>0.27; 0.27                                 | 0; 0.129; 0.129;<br>0.129; 0.129                             | 0; 0.079; 0.079;<br>0.079; 0.079               | 0; 0.057; 0.057;<br>0.057; 0.057              |    | 9.3; 10.3; 10.3;<br>10.3; 10.3             |
|                           | Beryllium (Be)          |    |    |   |    |  | 0.001; 0.001;<br>0.001; 0.001;<br>0.001                      |  |   |    | 0.022; 0.022;<br>0.022; 0.022;<br>0.022    |
|                           | Bismuth (Bi)            |    |    |   |    |  | 0; 0; 0; 0; 0  |  |   |    |  |
|                           | Boron (B)               |    |    |   |    | 0; 0.154; 0.154;<br>0.154; 0.154                             | 0; 0.021; 0.021;<br>0.021; 0.021                             | 0; 0.182; 0.182;<br>0.182; 0.182               | 0; 0.18; 0.18;<br>0.18; 0.18                  |    | 0; 0.56; 0.56;<br>0.56; 0.56               |
|                           | Cadmium (Cd)            |    |    |   |    | 0.000056;<br>0.000089;<br>0.000089;<br>0.000089;<br>0.000089 | 0.000067;<br>0.0001; 0.0001;<br>0.0001; 0.0001               | 0.000567;<br>0.0006; 0.0006;<br>0.0006; 0.0006 | 0.000167;<br>0.0002; 0.0002;<br>0.002; 0.0002 |    | 0.021967; 0.022;<br>0.022; 0.022;<br>0.022 |
|                           | Calcium (Ca)            |    |    |   |    |  | 97.8; 97.8; 97.8;<br>97.8; 97.8                              |  |   |    |  |
|                           | Chromium (Cr)           |    |    |   |    |  |  |  |   |    |  |
|                           | Cobalt (Co)             |    |    |   |    |  |  |  |   |    |  |
|                           | Copper (Cu)             |    |    | 0.026; 0.033;<br>0.033; 0.033;<br>0.033 |    |  |  |  |   |    |  |
|                           | Iron (Fe)               |    |    |   |    |  | 0; 0.06; 0.06;<br>0.06; 0.06                                 |  |   |    |  |
|                           | Lead (Pb)               |    |    |   |    |  |  |  |   |    |  |

**Table C 10: Water Test Data - Exceedances (Part 2)**

| Site                      |                 | 18 | 19 | 20                                      | 21 | 22 | 23   | 27 | 31 | 37 | 44 |
|---------------------------|-----------------|----|----|---|----|----|--|----|----|----|----|
| METALS & ELEMENTS - WATER | Lithium (Li)    |    |    | 18.7; 18.7; 18.7;<br>18.7; 18.7         |    |    |  |    |    |    |    |
|                           | Magnesium (Mg)  |    |    | 0.004; 0.004;<br>0.004; 0.004;<br>0.004 |    |    | 41.2; 41.2; 41.2;<br>41.2 ;41.2              |    |    |    |    |
|                           | Manganese (Mn)  |    |    |   |    |    | 0; 0.015; 0.015;<br>0.015; 0.015             |    |    |    |    |
|                           | Mercury (Hg)    |    |    |   |    |    |  |    |    |    |    |
|                           | Molybdenum (Mo) |    |    |   |    |    | 0.003; 0.003;<br>0.003; 0.003;<br>0.003      |    |    |    |    |
|                           | Nickel (Ni)     |    |    |   |    |    |  |    |    |    |    |
|                           | Phosphorus (P)  |    |    | 1.73; 1.73; 1.73;<br>1.73; 1.73         |    |    |  |    |    |    |    |
|                           | Potassium (K)   |    |    |   |    |    |  |    |    |    |    |
|                           | Selenium (Se)   |    |    |   |    |    |  |    |    |    |    |
|                           | Silver (Ag)     |    |    | 13.8999; 13.9;<br>13.9; 13.9; 13.9      |    |    |  |    |    |    |    |
|                           | Sodium (Na)     |    |    | 0; 0.269; 0.269;<br>0.269; 0.269        |    |    |  |    |    |    |    |
|                           | Strontium (Sr)  |    |    | 17; 17; 17; 17;<br>17                   |    |    |  |    |    |    |    |
|                           | Thallium (Tl)   |    |    |   |    |    |  |    |    |    |    |
|                           | Tin (Sb)        |    |    |   |    |    |  |    |    |    |    |
|                           | Titanium (Ti)   |    |    |   |    |    | 0.006; 0.006;<br>0.006; 0.006;<br>0.006      |    |    |    |    |
|                           | Uranium (U)     |    |    |   |    |    | 0; 0; 0; 0; 0                                |    |    |    |    |
|                           | Vanadium (V)    |    |    |   |    |    | 0.0012; 0.0012;<br>0.0012; 0.0012;<br>0.0012 |    |    |    |    |
|                           | Zinc (Zn)       |    |    |   |    |    |  |    |    |    |    |

