Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health

CCME SOIL QUALITY INDEX 1.0 Technical Report

Summary

Contaminated sites are of great concern for their potential impact on public and ecosystem health. Contaminated sites are found in every province and territory in Canada, as well as on federally owned lands. Therefore, tools for assessing the relative hazards or risks posed by various sites can be useful in prioritizing sites for remediation. The National Classification System for Contaminated Sites (NCSCS) provides a method, or screening tool, for assessing/rating various contaminated sites (CCME, 1992; CCME 2007-draft). Sites are classified under the NCSCS based on the known contamination and the potential for exposure to various receptors. The Soil Quality Index (SoQI) is a complementary tool that focuses more on evaluating the relative hazard, by comparing contaminant concentrations with their respective soil quality guidelines. Advantages of the SoQI include that it is relatively simple and easy to use, and is less subjective than the NCSCS.

The proposed SoQI uses three factors for its calculations, namely: 1) scope (% of contaminants that do not meet their respective guidelines), 2) frequency (% of individual tests of contaminants that do not meet their respective guidelines), and 3) amplitude (the amount by which the contaminants do not meet their respective guidelines). The proposed soil quality index can be used to compare different contaminated sites with similar types of contamination as well as to see if the jurisdictional requirements have been met after remediation of a particular site.

The basic requirements for calculating the SoQI for contaminated sites include: selection of applicable contaminants, measured concentrations of all relevant contaminants at the site, and their established soil quality guidelines. Some additional data about the site is also required for selecting the appropriate guidelines and applicable receptors. The Index provides a quantitative assessment of contaminated sites with a final value between 0 and 100. Using the final values of the SoQI, contaminated sites can be divided into five different classes based on the level of their concern to public or ecosystem health. The proposed classes are: Very low (90-100), low (70-90), Medium (50-70), High (30-50) and Very high (0-30).

The rating of a contaminated site can be further described by identifying the contaminants that are exceeding the guidelines and providing a brief statement about the required remediation and available soil management options. An example with actual data from a contaminated site is presented to illustrate how the proposed soil quality index is calculated and used. A spreadsheet model or calculator is available online (www.ccme.ca) for calculating the SoQI scores for contaminated sites.

Introduction

Contaminated sites and their potential impact on ecosystem and public health have been an area of great concern for a long time throughout Canada. In April 1990, a multi-stakeholder workshop (CCME Contaminated Sites Consultation Workshop) was held with representatives from government, industry and the public. At this workshop, it was agreed that a system was required to classify or rate the contaminated sites and it was recommended that the system should be relatively simple and applicable to all contaminated sites in Canada. As a result of this workshop, a National Classification System for Contaminated Sites (NCSCS) was developed to classify contaminated sites in Canada (CCME, 1992). A revised version of the NCSCS was later developed in 2003 for specific use at federal contaminated sites (Environment Canada, 2003). The system was designed as a tool specifically for the classification and general prioritization of contaminated sites. The system screens sites with respect to the need for further action to protect public and ecosystem health.

The primary purpose of the National Classification System is to evaluate the hazard potential of a site by scoring site characteristics that can be grouped under one of three categories, namely contaminant characteristics, exposure pathways and receptors that may be exposed to and affected by contamination. The system evaluates sites by scoring them on a scale from 0 to 100. A high score means that the site has a high potential for causing negative impacts. The system was not designed to provide a quantitative risk assessment but rather to screen sites with respect to the need for further action to protect ecosystem and public health. As it provides a numerical rating system, some people use this method not only as a qualitative but also as a quantitative tool.

The CCME Soil Quality Guidelines Task Group recently reviewed the 1992 National Classification System for Contaminated Sites. Numerous recommendations were made to make the classification system less subjective, and more applicable to a broader range of potential site conditions. Therefore, a revised classification system is currently under development.

The soil quality index (SoQI) differs in a number of ways from the NCSCS, and therefore makes a useful complementary tool for screening contaminated sites. Whereas the NCSCS considers the potential impact of the single worst contaminant present at a site, with the SoQI the impact of all relevant contaminants are assessed at one time in an integrated manner. There is considerably less potential for subjectivity in the classification of a site using the SoQI than with the NCSCS, as the SoQI is entirely determined based on analytical data, with user input only in the selection of relevant contaminants and appropriate guideline values. The NCSCS is broader in scope, in that it also involves assessing the potential for future migration of contaminants from the site and exposure to a wider range of receptors. In contrast, the SoQI focuses just on the current extent of the contamination and its exceedances of soil quality guidelines. The SoQI is therefore relatively simple and easy to use.

In using the SoQI, it is important to keep in mind its limitations. An advantage of the SoQI is that it provides the ability to combine various measurements into a single metric, and facilitates the communication of results. The SoQI is not intended to replace a detailed analysis of environmental monitoring data, nor should it be used as the only tool for management of contaminated sites. What it can do is provide a broad overview of environmental quality at various contaminated sites as a starting point for prioritizing further assessment or remediation efforts.

Background – Existing Similar Indices in Canada

The proposed soil quality index has been developed based on a similar formulation that was used in the Canadian Water Quality Index (CCME, 2001) and a sediment quality index (Grapentine et al. 2002 and Marvin et al. 2004). Prior to the development of the CCME water quality index, there were a number of jurisdictions in Canada using some type of indices to assess water quality. The Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment (CCME) formed a technical subcommittee in 1997 to assess different approaches and to develop an index that could be used to simplify water quality reporting in Canada. After reviewing the approaches from Quebec (Hébert, 1996), British Columbia (Rocchini and Swain, 1995) and Alberta (Wright et al. 1999), the technical subcommittee adopted the conceptual model from the British Columbia index and later finalized the index.

The proposed soil quality index is a quantitative tool to assess and rate contaminated sites. It can be used in communicating complex data in an understandable way. The index can also be used to compare the sites before and after remediation and to see if the jurisdictional requirements have been met for a particular site.

CCME Soil Quality Index Development

The basic requirements for using this index to assess or rate a contaminated site are as follows:

1) Selection of applicable contaminants;
2) Sample collection and contaminant analysis;
3) Site assessment data; and
4) Soil quality guidelines.

Selection of Applicable Contaminants

Selection of the contaminants is an important factor in calculating the soil quality index. The basic guidance for selecting contaminants is as follows:

1. Selected contaminants should have some relevance to the type of contamination that has occurred or the chemicals used in industrial operations in the past at that site.
2. One should also include known or expected by-products of contaminants where applicable.
3. Selected contaminants should have some established soil quality guidelines/standards.

A general list of contaminants cannot be proposed for contaminated sites, as the number and type of contaminants at any one site varies widely depending upon the type of industry or the spill at that site.

For example, sites contaminated with petroleum hydrocarbons (PHC) can include at least four fractions of PHC (F1: C6-C10; F2: C10-C16; F3: C16-C34; and F4:

>C34), benzene, toluene, ethylbenzene, xylenes, and lead. Sites contaminated with metals or pesticides will include all metals or pesticides respectively either spilled or used at the site during their operations. It may include some of their byproducts if they are of any public or ecological health concern. Sites contaminated with radioactive or other metals should include major metals along with other metals mined as impurities, their byproducts and chemicals used in their processing.

The sensitivity analysis of the SoQI (Gartner Lee Ltd, 2006) found that the average value of the SoQI increases as the number of contaminants is decreased, and the variability of the index also increases. In general, a minimum of four contaminants should be used in calculating the soil quality index for rating a contaminated site. However, if a site is contaminated with only one or two substances, one can still calculate the SoQI with fewer than four contaminants, but one should be careful in interpreting the results and such sites should not be compared with sites where a greater number of contaminants were used.

Sites with similar contamination issues, whose SoQI scores are to be directly compared should have the same parameters sampled at each site. The sensitivity analysis by Gartner Lee Ltd. (2006) also suggested that one should not exclude the major contaminants of the site in calculating the SoQI.

The total number of selected contaminants is very important for the index to yield meaningful results. Choosing a small number of contaminants for which the guidelines are not met will provide a different picture than if a large number of contaminants are chosen where most of them meet their guidelines.

In order to avoid any misuse of this tool, the user, as well as the regulatory officer, must ensure that the guidance in selecting the appropriate number and type of contaminants is followed in calculating the soil quality index. Failing to include relevant contaminants in the calculation, or conversely, loading up the calculation with data on irrelevant substances at a site, can both skew the index results and affect the ability to make fair and appropriate comparisons of scores among sites.

Sample Collection and Contaminant Analysis

Analytical data are required on the concentrations of all applicable contaminants from numerous soil samples collected at the site. Ideally, samples should be collected from various locations (horizontally) and at various soil depths (vertically) at the site in order to capture the range of distribution of the contamination. Recommended approaches for the collection of soil samples and contaminant analysis can be found in volumes I and II of the "*Guidance Manual on Sampling, Analysis, and Data Management for Contaminated Sites*" (CCME 1993a,b).

The total number of soil samples depends upon the required level of precision. Also, the locations (horizontal and vertical) within the contaminated site should be based on the mobility of various contaminants and history of contamination at that site. It must be left up to the professional judgment of the user for selecting the number of sampling locations including soil depths, number of contaminants, and total number of soil samples to be used for chemical analysis in calculating the soil quality index.

Site assessment data

Additional information on characteristics of the contaminated site is also required, especially for liquid or highly mobile contaminants. Data that should be collected include: soil texture, present and future land use, hydraulic conductivity, distances to nearby buildings and surface water sources and depth of the groundwater table.

For example, present and future land use and soil texture are useful in selecting the appropriate guidelines. Information on distances to nearly buildings and surface water sources will help in determining the applicable pathways and receptors for a Tier 2 approach where applicable. Similarly, hydraulic conductivity, soil texture of the confining layer and depth of the water table will help in determining any possible impact on groundwater sources around that site. Such information can also be used in developing the soil quality guideline if required for using Tier-2 at any particular site.

Soil Quality Guidelines

The role of soil quality guidelines in the successful implementation and reporting of the SoQI cannot be overstated. The ability of the SoQI to accurately "score" the quality of contaminated sites and the level of concern for public and ecosystem health depends directly on the use of appropriate guidelines against which monitoring data are compared. The key point is that the guidelines used in the SoQI computation should be locally relevant, meaning appropriate to the local assemblage of species, natural background and soil characteristics such as organic carbon content, particle size, pH and redox potential that can affect the toxicity of some chemicals of concern.

The guideline values could be national, provincial/territorial or site-specific in origin, so long as they fit the local conditions. For example national guidelines will likely be locally relevant if the toxicity of the substance is not modified by pH or redox potential, or if the national guidelines can be adjusted easily through an existing equation or model to accommodate the toxicity modifying effects of pH or redox potential. True site-specific guidelines involving site-specific assessment and toxicity testing will need to be developed for substances and sites for which national or other generic or provincial guidelines cannot be applied. For example, national values for naturally occurring substances (e.g., metals) will not likely be appropriate if the local natural background is high or if there are local sensitive species or species of concern to be considered.

Some of the criteria for selecting appropriate guidelines are described below.

In the case of petroleum hydrocarbons, there are two possible scenarios that may apply when selecting guidelines/standards for calculating the SoQI:

1. TIER-1 scenario: when the contamination is relatively small and it is economical and practical to remediate the contaminated site to the minimum guideline of all possible receptors of human and ecological health. In these cases, soil analyses may be compared directly with the Tier-1 values provided in the Canada-wide Standard for Petroleum Hydrocarbons in Soils (CCME, 2001a).

2. TIER-2 scenario: when the contamination is relatively large and it is not practical or economical to remediate the site to the minimum guideline of all possible receptors of human and ecological health; further, it is quite obvious that some of the pathways will not apply because of the location, land use or geology at that site. In these cases, a Tier-2 approach to develop site-specific guidelines should be used, as described in CCME (2001a).

Similarly, with other types of contaminants, concentrations may be compared directly with existing soil quality guidelines (i.e., a Tier-1 approach), or a Tier-2 approach can also be used to derive site-specific guidelines, if applicable.

Under Tier-1, the soil quality index should be calculated by using the most stringent guideline of all pathways and receptors for a specified land use. Under a Tier-2 scenario, pathways that are not applicable at the contaminated site will be eliminated and the most stringent guideline of all the applicable pathways and receptors will be used or modified guidelines will be developed if required, by using local site information and available models (CCME, 2001b).

A spreadsheet model was developed (CCME, 2003) for determining the most stringent guidelines of petroleum hydrocarbons for both scenarios. That model can be updated if significant changes in the guidelines are approved anytime in the future by CCME.

Soil quality guidelines for most contaminants are generally available for human health and environmental health under the four land use categories, namely: Agricultural, Residential / Parkland, Commercial and Industrial. The human health guidelines are further divided under different pathways, namely: soil ingestion (and/or particle inhalation and dermal contact); drinking water; inhalation of indoor air; offsite migration; and consumption of produce, meat and milk. Similarly, the environmental health guidelines are divided under: direct soil contact; soil and food ingestion; nutrient and energy cycling; groundwater (aquatic life, irrigation, and /or livestock watering); and offsite migration. Soil quality guidelines of many contaminants are not available for all the above pathways due to lack of available scientific data, or where a pathway is not applicable for a particular contaminant.

In view of the available soil quality guidelines, the soil quality index can be quite flexible for calculating the SoQI for human health or environmental health separately if required. Also the index can be calculated either for the applicable land use or can be further refined to use the most stringent pathway or receptor. The final value of the soil quality index and site-ranking category will vary widely with the selection of guidelines used for any contaminated site. If the basic information required for assessing various pathways and possible receptors at the contaminated sites is available or can be obtained, it is recommended that one should assess all pathways and receptors and use the most stringent soil quality guideline of the applicable pathways or receptor.

Selection of guidelines also depend upon the future land use of the area. The guidelines for calculating the SoQI should first be selected based on the future land use (agriculture, residential/parkland, commercial or industrial) of the area, followed by soil texture and for applicable receptors, if required.

CCME (1999) has published Canadian Soil Quality Guidelines for about 70 chemical substances. For detailed information on the soil quality guidelines for various contaminants, please refer to chapter 7 of *Canadian Environmental Quality Guidelines* (CCME 1999). A summary table of the guideline values is also available on the CCME website at http://www.ccme.ca/publications/ceqg_rcqe.html?category_id=124. Information on the Canada-wide standards for petroleum hydrocarbons is also available at http://www.ccme.ca/ourwork/soil.html?category_id=43. These guidelines are provided for four land uses (agricultural, residential/parkland, commercial and industrial) and for various receptors of human and ecological health. Some provinces in Canada develop and use their own provincial or site-specific guidelines (e.g., Quebec, Ontario, Alberta, British Columbia) while others adopt CCME's guidelines as such or modify them for their use based on the background concentrations and other local conditions.

Under the general guidance of the United States Environmental Protection Agency (USEPA), various states of the U.S.A. have developed soil quality guidelines/standards for over 200 chemicals. For example, the soil quality guidelines developed by Michigan Department of Environmental Quality (2004) are available at their website (http://www.deq.state.mi.us/documents/deq-rrd-part201-rules-Rule746Table.pdf). If appropriate guidelines are not available in Canada for a particular contaminant, U.S. guidelines may be considered for use in calculating the soil quality index. However, this should be done with caution, as guidelines from the U.S. are developed using different procedures and may also have different levels of protection than Canadian Soil Quality Guidelines. Soil quality guidelines have also been published by various European countries, which are also accessible if required.

Site-specific soil quality guidelines are always preferred when available. However, in their absence, use of provincial or national soil quality guidelines is recommended. If a jurisdiction does not have guidelines for all contaminants of interest for a site, a mix from different jurisdictions could be considered. However, in using a mix, it would be preferable if the approach used in deriving their guidelines is comparable and they are based on comparable levels of protection. The SoQI Calculator (available online at www.ccme.ca/) includes the Canadian Soil Quality Guidelines as the default option; however, other guidelines may be added to the calculator by the user.

CCME Soil Quality Index Formulations

The SoQI for contaminated sites was developed by using three factors, namely: F1 (Scope), F2 (Frequency), and F3 (Amplitude). A brief description of these factors and formulae for calculating the index are as follows:

F1 (Scope)

The factor F1 (as calculated in equation 1) represents the percentage of contaminants that do not meet their respective guidelines (failed contaminants) relative to the total number of contaminants that were measured (and selected for inclusion in the SoQI calculation) at the site.

$$F_1 = \frac{Number\ of\ failed\ contaminants}{Total\ number\ of\ contaminants} x\,100 \ldots (1)$$

F2 (Frequency)

The factor F2 (equation 2) represents the percentage of individual tests that do not meet their respective guidelines (failed tests):

$$F_2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} x\,100 \quad \ldots\ldots\ldots\ldots (2)$$

F3 (Amplitude)

The factor F3 (equation 5) represents the amount by which failed test values do not meet their respective guidelines (excursion from the guideline value). The relationship between F3 and the amount by which the concentrations of contaminants depart from their guidelines are described by Wright et al. (1999). F3 is calculated in the following three steps.

Step 1: Calculate the excursion of all tests in the dataset:

When the concentration of a contaminant is greater than (or less than, when the guideline is a minimum) the soil quality guideline, it is called an excursion. The magnitude of excursion of each test is calculated as follows:

When the test value must not exceed the guideline:

$$Excursion_i = \frac{Failed\ Test\ Value_i}{Guideline_i} - 1 \quad \ldots\ldots (3a)$$

For the cases in which the test value must not fall below the guideline:

$$Excursion_i = \frac{Guideline_i}{Failed\ Test\ Value_i} - 1 \quad \ldots\ldots(3b)$$

Step 2. Calculate the average sum of excursions or 'ase'

This refers to the average amount by which individual tests are out of compliance and is calculated by summing the excursion of all individual tests from their guidelines and dividing by the total number of tests that do not meet their guidelines as follows:

$$ase \quad = \quad \frac{\sum_{i=1}^{n} excursion_i}{\#\ of\ \ failed\ tests} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

In the water quality index (CCME, 2001), rather than calculating the 'ase', the 'normalized sum of excursions' or 'nse' was calculated by dividing the sum of excursions by the total number of tests (tests that meet as well as those that do not meet the guidelines). By using 'nse' instead of 'ase', factor F3 becomes smaller and increases the value of the soil quality index. The impact of using 'nse' is that both F3 and the final value of the soil quality index increase with an increase in the total number of tests. Therefore, for the purposes of the SoQI, F3 has been modified to use 'ase', where the sum of excursions is divided by only the total number of tests that are not in compliance (equation 4). The main reasons for this change are as follows:

1. As the quality of a contaminated site is primarily judged by the amount of excursions of various contaminants from their guidelines, the value of F3 should appropriately reflect that in comparison to F1 and F2.

2. The effect of contaminants gets diluted by dividing the excursions by the total number of tests.

3. Any one of the contaminants that is not in compliance can cause severe limitations for the ecosystem or public health. Therefore, the impact of any contaminant should not be minimized in rating the contaminated site.

Step 3. F3 is then calculated by an asymptotic function that scales the average sum of excursions (ase) to yield a range between 0 and 100 as follows:

$$F3 \quad = \quad \frac{ase}{0.01\,ase \quad + \quad 0.01} \quad \ldots\ldots\ldots\ldots\ldots(5)$$

The Soil Quality Index (SoQI)

Once the factors have been quantified, the SoQI can be calculated by summing all the factors as if they were vectors as shown below in equation # 6. This approach treats the index as a three dimensional space defined by each factor along one axis. With this model, the index changes in direct proportion to changes in all three factors

$$SoQI = 100 - \frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \quad \ldots\ldots\ldots\ldots(6)$$

The divisor (1.732) normalizes the resultant values to a range between zero and one hundred, where zero represents a very high level of contamination or public concern and one hundred represents negligible amount of contamination or public concern. The value of the divisor is calculated as follows:

$$\frac{\sqrt{100^2 + 100^2 + 100^2}}{100} = 1.732 \quad \ldots\ldots\ldots\ldots\ldots(7)$$

If a site is not tested more than once over time or space, the Factor F2 (frequency) won't be applicable and the divisor for the equation (6) for calculating the SoQI will be 1.414. Although contaminated sites may not be tested more than once over time, typically they are tested over a wide area or space, i.e., with various samples collected vertically at different depths and horizontally at different distances from the main site of contamination to determine the total spread of contamination. As a result, all samples taken both in horizontal and vertical directions make the Factor 2 applicable for its use in calculating the soil quality index.

Based on the final value of the index, contaminated sites can be divided into five different classes as follows. Each class of contaminated site needs to be interpreted based on the level of concern for public and ecosystem health and the need for remediation. Sites with a high SoQI score (e.g., 90-100) are of high quality and have a very low level of concern. Therefore, these would be low priorities for remediation. At the other end of the scale, a low SoQI score (0-30) would indicate a very high level of concern due to contamination, and therefore a high need for remediation.

It is important to note that in the NCS method of assessing contaminated sites, a high score means a high potential and a low score means a low potential or concern for negative impact. On the other hand, in the soil quality index, the scoring and categories are opposite to the NCS method and are designed to be consistent with the CCME's water quality and sediment quality indices.

Site Classes or Level of concern	***Soil Ranking Categories of the SoQI***
Very Low	90-100
Low	70-90
Medium	50-70
High	30-50
Very high	0-30

When reporting SoQI scores for contaminated sites, users should also provide a list of major contaminants of public concern and a statement describing the need for soil remediation or soil management options where possible.

An Example of Calculating the SoQI for Contaminated Sites

This case study is a site located in Saskatchewan that was found to be contaminated with petroleum hydrocarbons and later remediated by using a Tier-1 approach. The soil samples were taken from four different locations and analyzed for benzene, ethylbenzene, toluene, xylenes, petroleum hydrocarbons F1 (C6-C10), F2 (C10-C16), F3 (C16-C34), F4 (C34-C50), and lead. The analytical data and applicable soil quality guidelines are presented below in Table 1.

<u>Calculation of the SoQI for case study:</u>

$$F1 = \frac{5}{9} x 100 = 55.6$$

$$F2 = \frac{6}{36} x 100 = 16.7$$

$$F3: \quad Excursion-i = \frac{40}{5} - 1 = 7$$

$$Excursion-ii = \frac{82}{50} - 1 = 0.64$$

$$Excursion-iii = \frac{220}{50} - 1 = 3.4$$

$$Excursion-iv = \frac{2840}{1000} - 1 = 1.84$$

$$Excursion-v = \frac{100}{30} - 1 = 2.3$$

$$Excursion-vi = \frac{180}{50} - 1 = 2.6$$

$$ase = \frac{17.78}{6} = 2.96$$

$$F3 = \frac{2.96}{(2.96 \, x \, 0.01 + 0.01)}$$

$$F3 = \frac{2.96}{0.0396} = 74.8$$

$$SoQI = 100 - \frac{\sqrt{55.6^2 + 16.7^2 + 74.8^2}}{1.732}$$

$$SoQI = 100 - 56 = 45$$

Conclusions of case study:

Level of concern: High

Type of Contamination: Soil is contaminated with benzene, ethylbenzene, toluene, xylenes and PHC fraction F1 (C6-C10).

Management Options: The soil should be remediated to the levels of Saskatchewan guidelines and Canada-wide standards for PHC fraction F1.

Table 1. Soil sample analysis of a commercial site contaminated with petroleum hydrocarbons.

Parameter	West wall mg/kg	Bottom mg/kg	North wall mg/kg	South wall mg/kg	Saskatchewan Subsoil Guidelines**
Depth (m)	2.4	5.3	2.4	3.0	-
Benzene	0.8	1.1	0.5	**40**	5.0
Ethylbenzene	27	0.8	4.7	**82**	50
Toluene	**100**	2.0	0.8	14	30
Xylenes	**180**	4.5	7.8	**220**	50
PHC F1	820	96	140	**2840**	1000
PHC F2	130	8.9	21	180	3000
PHC F3	<5	<5	<5	<5	5,000
PHC F4	<5	<5	<5	<5	10,000
Lead	10	8	8	16	1000***

Data exceeding the Saskatchewan guidelines are shown in **BOLD** and shaded

< Not detected at level stated

** Saskatchewan's Interim Criteria of BTEX and PHC fractions of soils for the year 2003

*** Saskatchewan's 'Risk Based Corrective Actions for petroleum contaminated sites, November 1995'

Sensitivity Analysis

There are some major differences in the formulations of the SoQI in the second and third factors and range of site ranking categories compared to the WQI. In view of these differences, the Soil Quality Guidelines Task Group of CCME initiated a study to carry out a sensitivity analysis of the proposed soil quality index. Major tasks of this study were as follows:

1. Carry out a sensitivity analysis of using 'nse' vs. 'ase' in calculating the factor F3.
2. Investigate the effects of other potential modifications to F1 and F2 and compare this with the results of the sensitivity analysis conducted for the Water Quality Index.
3. Evaluate the sensitivity of the SoQI to the number of contaminants used, selection of guidelines and the selection of contaminants.
4. Evaluate the proposed SoQI site ranking categories.
5. Compare the site assessment results obtained by using the SoQI versus classification scores determined using the NCSCS method.

Gartner Lee Limited carried out the study and submitted their report to the SQGTG of CCME in April 2006 (Gartner Lee Ltd., 2006). They examined over 600 contaminated sites with over 50,000 analytical measurements. Their conclusions were as follows:

a. The SoQI is sensitive to a variety of inputs, as is required for an index to reflect changes in the characteristics of the sites it is supposed to reflect.
b. Of the four alternative formulations of the SoQI considered, the one proposed by Jain (2007) and used here in this fact sheet appears to be the preferred formulation, based on the relatively evenly distributed influence of the three factors that comprise the index and correspondence to an independent assessment methodology already used for contaminated sites.
c. Contaminant selection should be based on measurements of soil quality relevant to the site. There appears to be no simple "rule of thumb" for selecting an optimal set of contaminants.
d. The SoQI is sensitive to the number of contaminants used for its calculation. In general, the SoQI value increases as the number of contaminants is decreased, and the variability of the index also increases.
e. The SoQI responds in the expected manner to changes in guidelines, yielding higher scores (better site quality assessment) with less stringent guidelines and lower scores (poorer site quality assessment) with more stringent guidelines.
f. In the database considered, there was a median 32 samples for 7 contaminants taken at each site. If this is representative of the typical sampling effort at a contaminated site, it appears to be adequate for assessment using the SoQI.
g. There is an overall (inverse) correspondence between the SoQI score for a site and the NCSCS score, with a significant ($p<0.05$) correlation. There is also a

correspondence between the SoQI score and the overall categorical ranking of the site using NCSCS nominal classifications, but on individual sites there may be significant differences. These differences may be due to fundamental differences in the site factors considered in the two scoring systems.

h. There is an opportunity for further investigation into the specific reasons for discrepancy between the SoQI and NCSCS evaluation systems.

Further details of the sensitivity analysis are available in the Gartner Lee Ltd. (2006) report.

Acknowledgements

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