A COMPARISON OF ECOLOGICAL RISK ASSESSMENTS DONE FOR THE DEW LINE SITE AT SARCPA LAKE, NUNAVUT; A CONVENTIONAL RISK ASSESSMENT VERSUS THE TERRASYS© MODEL

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ABSTRACT

Contaminated sites in Nunavut and Northwest Territories represent a large proportion of the Canadian government's liability from contaminated sites. Under the Federal Contaminated Sites Accelerated Action Plan (FCSAAP) one of Environment Canada's responsibilities is to develop tools for rapid assessment of sites. Standardized approaches to conducting ecological risk assessments is also a desirable endpoint for the federal government's FCSAAP program as it enables a more equal comparison between sites. Sanexen Environmental Services's TerraSys© environmental risk assessment model for contaminated sites shows considerable promise as such a tool. This paper describes our evaluation of the model to validate TerraSys© for use in assessing northern contaminated sites. The use of such a model may also enable federal government departments to conduct reliable, standardized ecological risk assessments without relying on a large staff of professional risk assessors, thereby reducing the cost to the federal government.

Considerable effort was needed in working with Sanexen to adapt the model to large, northern contaminated sites. Several versions of the model were developed and tested to generate the results described in this paper.

Results from the TerraSys© environmental risk assessment model were compared to those from a more conventional risk assessment to determine the model's potential value as a risk assessment tool. The Distant Early Warning (DEW) Line site at Sarcpa Lake (CAM-F) was chosen because both site assessment and risk assessments are complete and remediation work has already begun allowing further confirmation of predictions.

CAM-F is an abandoned radar station, formerly part of the DEW Line, contaminated with heavy metals and polychlorinated biphenyls (PCBs). There is the potential for these contaminants to travel from the soil into the terrestrial food chain, and into the nearby lake affecting the aquatic food chain. Sarcpa Lake is a nesting ground for many migratory bird species which could be negatively impacted by contamination. Other animal species of value to both humans and animals as food sources use the area and could also be at risk.

The TerraSys© model allows the user to design the risk assessment to suit their needs. In this assessment, the goals and parameters of the model were kept as close to those of the original assessment as possible, the purpose being to compare the results with as little difference in the underlying assessment methodology as possible, while evaluating the process of assessment.

The results indicate that the predictions of the model are similar to those of the conventional risk assessment. For example, the risk quotients for PCBs were found to be within an order of magnitude and in all but one case, the same receptors were deemed to be at risk. This is generally considered to be acceptable results for a model.

INTRODUCTION

Ecological risk assessments (ERAs) can be used as one of three approaches for the development of site specific remediation plans (CCME 1997). An ERA has the advantage of using more site specific information than the other two options: the adoption of environmental quality criteria either directly or with limited modifications. However, ERAs can be time-consuming, expensive, usually require expert contractors, and non-standardized.

The potential advantages of a model include: lower cost, less field time, less experienced researchers are necessary, and consistency from one assessment to the next. However, these advantages depend on the validity of the model.

Conducting an ecological risk assessment with TerraSys© is similar to the way professionals conduct risk assessments. They both consist of 4 major steps:
1. Receptor Characterization consists of identifying components of the ecosystem that could be adversely affected;
2. Exposure Assessment determines whether the receptor will co-occur with the stressor and estimates the level of exposure;
3. Hazard Assessment evaluates the type and magnitude of the effect caused by the stressor;
4. Risk Characterization estimates the likelihood of a negative effect to the receptor (CCME 1996).

The differences between a conventional risk assessment and TerraSys© are:

1. TerraSys© is able to use default toxicological values for many substances, eliminating a time consuming step of searching for toxicity data and eliminating a possible source of variation by using the same data for risk assessments. The TerraSys© user is also able to enter their own toxicological parameters.
2. The conceptual model in TerraSys© includes more exposure pathways, whether they are considered to be significant or not.
3. Receptor characterization data developed for one northern site can be used for all northern sites, thereby increasing ease of use for later assessments and to standardize receptor-specific data.
4. TerraSys© is capable of geostatistical modeling of the movement of contaminants through soil based on physical-chemical characteristics of the contaminants, soil characteristics and precipitation patterns at the site.
5. TerraSys© uses the same risk assessment equations for all assessments, thereby increasing the standardization of this process.
6. TerraSys© includes a risk characterization, but goes one step further by providing suggestions for the interpretation of results. Professional judgement is still required for a full analysis of the results.
7. TerraSys© has the ability to calculate the risk to each receptor through many different methods. It can use: reference concentration; the distribution of toxicological endpoints based the desired effect level (NOAEL, LOAEL, ED50 and CD50); or the raw ecotoxicological data at a user defined effect level.
8. TerraSys© can estimate direct risk from contaminants, indirect risk from loss of prey or habitat, and indirect benefit by negative effects on competitive or predatory species.
9. TerraSys© will model receptor contaminant concentrations based on measured soil concentrations and modeled sediment and water concentrations. It , however, it will also accept receptor concentration data into the conceptual model if it is available.
10. TerraSys© contains a set of toxicological databases derived from peer-reviewed literature. These databases allow the user to conduct ecotoxicological risk assessments on receptor-contaminant combinations for which there are no toxicological data (Sanexen 2002). For example, TerraSys© is able to estimate the toxicity of a substance to lemmings based on toxicity data for a similar organism, and then scales that value to a lemming based on size and body weight. In this way risk estimates can be generated on novel contaminant-receptor combinations. The user is also able to enter specific information to enable this type of estimation for site-specific contaminants and species.

An initial site assessment was performed at CAM-F by Royal Roads Military College (RRMC 1994). The data collected in that survey was used in both the QC assessment and in TerraSys©. The ERA performed by the Qikiqtaaluk Corporation (QC) was conducted to identify potential risks to valued ecosystem components (VECs). VECs are “resources or environmental features that are important to human populations; have local, regional, provincial, national and/or international profiles; or if altered from their existing status, will be important in evaluating the impacts of development and in focusing management or regulatory policy” (CCME 1996). The significance of their damage or loss to ecosystem health was also considered in this assessment. On-site contamination of soils with PCBs and heavy metals and the effects on the local ecosystem were studied (QC et al. 1998). The goals and methods of the TerraSys© assessment followed these guidelines as closely as possible within the framework of the model to ensure comparability.

Objectives

The objectives of the QC ERA were to “determine whether the on-site soil contamination at the abandoned DEW line sites would likely pose risks to indigenous terrestrial wildlife species and aquatic life, relative to comparable non-contaminated sites or background areas; and to identify areas within the abandoned DEW line sites which may potentially require remediation (based on potential ecological risks)" (QC et al. 1998).

The TerraSys© ERA was done with the same objectives to test the validity of the modeling system, and to make the conclusions of the QC ERA comparable with those of the model.

METHODS

Qikiqtaaluk Corporation Methods

The QC assessment of terrestrial wildlife risk followed the framework of preliminary quantitative ERA as outlined by Gaudet et al. (1994) and the CCME (1996). The underlying principle in their decision making process was to make conservative yet realistic assumptions (QC et al. 1998).

The ecological receptors selected by the QC, and shown in Table 1, were chosen to be applicable to the 5 DEW line sites they were assessing and to represent VECs. Receptors not selected as VECs were assessed only in their capacity to pass on contamination to a VEC; risk quotients were not calculated for vegetation, soil dwelling organisms, or aquatic organisms.

QC		TerraSys©	
Vegetation	*	Herbaceous vegetation	*
		Shrubs	*
Soil Dwelling Organisms	*		X
Soil Micro-organisms	*		X
Aquatic Organisms	*	Aquatic Micoorganisms	*
		Phytoplankton/ Periphyton	*
		Aquatic Invertebrates	*
		Zooplankton	*
		Lake Trout	*
Lemming	*		*
Arctic Hare	*		*
Caribou	*		*
Snow Goose	*		X
Arctic Fox	*		*
Northern Hawk/Snowy Owl	*		*
Glaucous-winged Gull	X		*
Rock Ptarmigan	X		*
White-rumped Sandpiper	X		*

* used in the ERA
X not used in the ERA

Table 1. Ecological receptors used by the QC and in TerraSys© in the ERA of Cam-F.

The possible exposure pathways for each receptor were determined through professional judgement (Table 4). The QC determined that some pathways were not significant sources of exposure and chose not to include them in their assessment (QC et al. 1998).

The QC made the assumption that the arctic fox, arctic hare and lemming spent 100% percent of their time on site and that the caribou and northern hawk spent 25% of their time on site.

The QC assessed the risk to terrestrial receptors at both the No Observed Adverse Effect Level (NOAEL) and the Lowest Observed Adverse Effect Level (LOAEL). They used the mean and maximum contaminant concentrations on site and at background locations to estimate exposure via the significant pathways; the soil concentrations were obtained from the site assessment done by the Royal Roads Military College (1994) (Table 2).

	Mean	Max	Guideline
Cu	27.26	94	63
Ni	15.08	28	20
Co	5.62	11.2	10
Cd	1.86	19.2	10
Pb	75.31	800	140
Zn	304.59	5740	200
Cr	42.34	93	64
As	0.66	1.7	12
PCB	2.69	38	0.1

Table 2. Soil contaminant concentrations at CAM-F and the CCME (1996) Canadian Soil Quality Guidelines, all in mg/kg.

Toxicity values were selected from the literature, and professional judgement was used to select NOAEL and LOAEL values. These exposure limit values were used to calculate the risk to each receptor using the equation (QC et al. 1998):

$$ExposureRatio = \frac{EstimatedExposure}{ExposureLimit}$$

TerraSys© Methods

The ecological receptors used in the model were selected to be representative of various trophic levels (Table 1). The glaucous-winged gull, rock ptarmigan and white-rumped sandpiper were chosen because they are common breeders at the site (Montgomerie et al. 1983). The VECs used in the QC assessment were also used to allow comparison, despite the fact that they had not been observed on site (RRMC 1994). The exception to this was the "northern hawk" receptor used by the QC. It is unclear which species this referred to, so the snowy owl was used as a representative of a large raptor instead.

TerraSys© assessed the risk to both herbaceous vegetation and shrubs, in addition to their capacity to transfer contaminants from the soil to terrestrial receptors.

The same pathways that were identified by the QC were used in the TerraSys© model (Table 4). Some professional judgement was necessary in this portion of the TerraSys© ERA to ensure that all possible routes of exposure were modelled. TerraSys© did not discriminate which routes were major sources of contamination and which were minor; all were modelled and then summed.

The same assumptions regarding time in the area were made in the TerraSys© ERA; migratory animals were assumed to be in the area only in the summer months, or 25% of the year, while other receptors were assumed to be present year round. TerraSys© has additional ability to model the feeding range of receptors based on their body weight, following Harestad and Bunnel (1979), (Table 3), so they were not restricted to feeding only on site, as were the animals in the QC ERA.

Receptor	Feeding Range (m^2)
Arctic Fox	6.43×10^7
Snowy Owl	4.03×10^6
Caribou	2.4×10^6
Hare	1.08×10^5
Brown Lemming	1.59×10^3

Table 3. Receptor feeding ranges as estimated by TerraSys© following Harestad and Bunnel (1979).

TerraSys© has the ability to calculate the risk to each receptor based on either the NOAEL or the LOAEL using the mean, max and background contaminant concentration values. The value used for the NOAEL or LOAEL was selected by TerraSys© from its database of ecotoxicological information.

The risk to each receptor was calculated by the equation (Sanexen 2002):

$$RI_R = \frac{L_{\exp_r}}{L_{threshold_r}}$$

where:

RI_r	risk index for receptor r
$L_{\exp_r}$	exposure level of receptor r
$L_{threshold_r}$	level presumed safe for receptor r (either the NOAEL or the LOAEL)

After calculating RI values, TerraSys© is able to complete an in-depth analysis of the results. This includes estimates of direct and indirect risks and indirect benefits, as well as an estimate of the level of confidence in these suggestions.

QC		**TerraSys©**	
Plants	Root uptake, deposition on leaves, vapor uptake through leaves.	**Herbaceous Vegetation**	Direct contact, root absorption, rain splash, foliar fixation.
		Shrubbery	Same as above
Soil Dwelling Organisms	Ingestion, dermal contact	X	
Soil Microorganisms	Continual contact	X	
Aquatic Organisms	Uptake through gills and skin, ingestion of contaminants bound to sediment, bioconcentration	**Aquatic Micro-organisms**	Direct contact with sediment and lake water.
		Phytoplankton/ Periphyton	Direct contact with sediment and lake water.
		Aquatic Invertebrates	Direct contact and ingestion of sediment and lake water.
		Zooplankton	Direct contact with sediment and lake water.
		Lake Trout	Bioconcentration, ingestion, and direct contact with sediments, water, prey
Lemming	Ingestion of contaminated soils, dust, surface water, vegetation, and dermal contact.		Ingestion of soil, lake water vegetation, direct contact with soil and herbaceous vegetation, inhalation of atmosphere.
Arctic Hare	Same as above		Same as above
Caribou	Same as above		Same as above
Snow Goose	Same as above	X	
Arctic Fox	Ingestion of contaminated soils, dust, surface water, prey, and dermal contact.		Ingestion of lake water, prey, direct contact with soil and herbaceous vegetation, inhalation of atmosphere
Northern Hawk	Ingestion of contaminated prey.	**Snowy Owl**	Ingestion of prey, direct contact with soil, inhalation of atmosphere
Glaucous-winged Gull	X		Inhalation of atmosphere, prey.
Rock Ptarmigan	X		Inhalation of atmosphere, ingestion of soil, water and vegetation, direct contact with soil and vegetation.
White-rumped Sandpiper	X		Inhalation of atmosphere, ingestion of sediment, water, prey.

X not used in ERA

Table 4. Exposure pathways for each receptor used by the QC and/or in TerraSys©.

RESULTS

Multimedia Concentrations

The initial site assessment sampled vegetation (RRMC 1994). When these observed values were compared to the values modeled by TerraSys©, using soil concentration data, it was found they were within an order of magnitude (Table 5).No other receptors were sampled by RRMC, preventing further comparison.

	Modelled	**Observed**
Herbaceous Vegetation		**N=3**
PCB	12.51	61.20
As	0.23	0.23
Cd	0.41	<0.5
Cr	1.31	8.43
Co	1.62	<5
Cu	0.92	7.60
Pb	4.85	<15
Ni	0.85	<5
Zinc	137.29	28.00

Shrub		**N=13**
PCB	10.09	14.35
As	0.05	<0.2
Cd	0.23	1.29
Cr	0.05	8.31
Co	0.00	<5
Cu	0.44	7.72
Pb	4.65	<15
Ni	0.02	<5
Zinc	127.10	258.15

Table 5. Modeled and observed contaminant concentrations (ppm) in herbs and shrubs.

Risk Characterization

In this paper the QC and TerraSys© assessments estimated risk to each receptor based on the NOAEL or the LOAEL using the mean, max and background contaminant concentration values and toxicity values from the literature. The Exposure Ratio (ER) generated by the QC assessment and the Risk Index (RI) generated by TerraSys© are assumed to be equivalent, called RI in this paper. The results of the NOAEL assessment using the mean soil contaminant concentration values are presented for comparison in Table 6; only RI greater than one are shown.

The estimates of risk due to PCBs were within an order of magnitude for the hawk/owl, lemming, and arctic hare. TerraSys© estimated that PCBs would pose a risk to caribou while the QC did not. The QC estimated that heavy metals could pose a risk to all receptors, while TerraSys© did not.

	QC	**TerraSys©**
Caribou		
Pb	**16**	0.028
PCB	0.0042	**2.45**
Fox		
Cd	**5**	0.000358
Pb	**1000**	0.0033
PCB	**28**	0.1
Hare		
As	**1**	0.034
PCB	**4.5**	**3.14**
Lemming		
PCB	**2.1**	**1.77**
Hawk/Owl		
Cd	**1.2**	0.049
Pb	**2.5**	0.13
PCB	**24**	**11.89**

Table 6. RI>1 at the NOAEL, using mean contaminant concentrations, as predicted by TerraSys© and the QC.

Most of the additional receptors included in the TerraSys© assessment were found to be at risk, except for the white-rumped sand-piper. Herbaceous vegetation and shrubs were most at risk due to zinc contamination while terrestrial invertebrates were threatened by lead contamination and rock ptarmigan and glaucous-winged gull were threatened by PCBs.

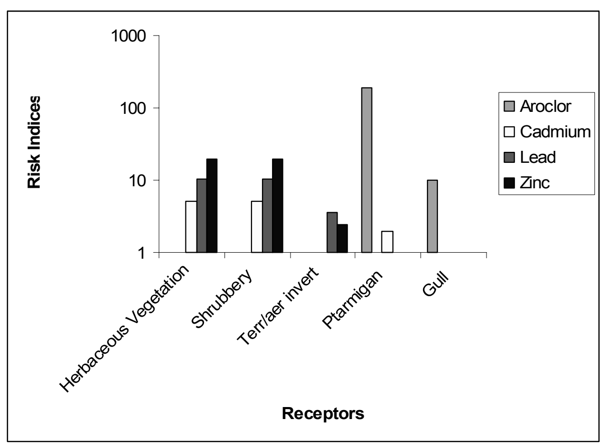

Fig 1. Risk Indices of receptors evaluated only in TerraSys©.

Interpretation of the Results

This analysis suggests which receptors face significant risk and which are not at risk (Table 7). The degree of confidence associated with all of these estimates is moderate. Table 8 shows the estimated direct and indirect risks and indirect benefits at CAM-F.

At Risk	Not at Risk
Herbaceous vegetation	Lake Trout
Shrubbery	Aquatic invertebrates
Arctic Hare	Phytoplankton/periphyton
Rock Ptarmigan	Aquatic microorganisms
White-rumped Sandpiper	Zooplankton
Glaucous-winged gull	Arctic Fox
Brown Lemming	
Caribou	
Terrestrial invertebrates	
Snowy Owl	

Table 7. Receptors deemed to be at risk and not at risk by TerraSys© at a moderate degree of confidence.

Receptor	Direct Risk	Indirect Risk	Indirect Benefits
Herbaceous vegetation	++	No	No
Shrubbery	++	No	No
Lake Trout	-	No	Yes
Arctic Hare	++	Yes	Yes
Rock Ptarmigan	++	Yes	Yes
White-rumped Sandpiper	++	Yes	Yes
Glaucous-winged gull	++	Yes	Yes
Brown Lemming	++	Yes	Yes
Caribou	++	Yes	Yes
Aquatic invertebrates	-	No	No
Phytoplankton/periphyton	-	No	No
Aquatic microorganisms	-	No	No
Zooplankton	-	No	No
Terrestrial invertebrates	++	No	No
Snowy Owl	++	Yes	Yes
Arctic Fox	-	Yes	Yes

- : No risk
+ : significant but not large risk
++ : significant and important risk

Table 8. Qualitative Assessment of the Indirect Risk and Benefits to Receptors generated by TerraSys©.

The QC concluded that PCBs were a potential risk to receptors, but that cadmium and zinc did “not represent an unacceptable risk to wildlife” and there was “no lead risk” when the background levels are taken into account (QC et al. 1998).

DISCUSSION

The comparison of modeled and observed contaminant loads in herbs and shrubs was included to demonstrate the accuracy of the TerraSys© contaminant uptake models. The differences noted were relatively small and could likely be accounted for by the small sample size take by RRMC.

The risk estimation methods used in each ERA were comparable and did not appear to contribute to the differences in results. The assumptions made in each risk assessment model seemed to account for the majority of the differences.

TerraSys assumed that sampled soil contaminant concentration values that were less than the detection limit were equal to half the detection limit. The QC assessment assumed such values were equal to the detection limit. This increased the exposure estimate in the QC assessment and may account for some of the differences in their risk estimates, especially for lead which had a very high detection limit.

The discrepancies that were noted between the Risk Indices were likely due to the differences in exposure estimation methods. Specifically, in the estimation of time spent on site and feeding range.

This difference was greatest in the estimation of risk to arctic fox and caribou. The QC estimated significant risk to the fox from cadmium, lead and PCB contamination, while TerraSys© estimated there would be no risk. The QC estimated significant risk to caribou from lead, while TerraSys© estimated they would be at risk only from PCBs.

The fox had the largest range of all the receptors, as estimated by TerraSys©, explaining the significantly lower risk estimated by TerraSys©. The QC assumed that the fox spent all of its time on site, increasing its exposure and its risk. The caribou’s large feeding range could also explain the decreased risk from lead estimated by TerraSys©. The inclusion of a feeding range in the TerraSys© model reduced the time on site by large receptors because the site was smaller than their feeding range, this in turn reduced the receptor’s estimated exposure to contaminants.

The caribou feeding range could not explain the risk to caribou from PCBs that was estimated by TerraSys©. This difference, however, could be explained by the assumed diet of caribou. The QC did not publish the quantities of herbs, shrubs, and non-vascular plants that they assumed the caribou were consuming. It is possible that the values entered into TerraSys©, taken from an unpublished Canadian Wildlife Service (CWS) report (Kelsall 1957), were different enough to alter the estimation of uptake and hence, risk.

In the case of the sandpiper, diet may explain why it is not at risk as estimated by TerraSys©. It ingests primarily aquatic invertebrates which are not exposed to the soil contaminants at the site. Also, its habitat was along the shoreline, away from the sources of contamination. Together, these two factors prevent the sandpiper from exposure through either direct contact or ingestion.

Except for the arctic fox, the two ERAs are in agreement as to which receptors are at risk. The QC concluded that metal contamination was not of concern, explaining that the risk indices they calculated did not indicate an unacceptable level of risk. They determined that PCBs were the major threat. The results produced by TerraSys© support this conclusion. Both ERAs also agree that there is no risk to aquatic systems.

A significant omission of both assessments is the lack of a module for non-vascular plants. Both lichens and mosses play an important role in production, nutrient sequestering, determination of soil thermal regime and evaporation from the soil surface, particularly at higher latitudes (Tenhunen *et al.,* 1992). Lichens are also a major food source for caribou. Because TerraSys© is modular, there is the potential to incorporate non-vascular vegetation to the software; Sanexen, the developers of TerraSys©, are currently looking into this possibility.

Based on these results, TerraSys© has shown that it can generate a screening level risk assessment with limited data that is comparable to one done by professionals. Information gaps are filled with either default or modeled values. As with all models, the more real world data available, the more likely the results are to be accurate; more information equals more certainty.

It has also proven to be usable by operators with limited knowledge of risk assessment who have a basic knowledge of biology and contaminant interactions, with supervision by skilled professionals. It should also be usable as a standardized approach to site risk assessment with little modification for the Arctic biome. This benefit can easily be transferred to other biomes in Canada.

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