Classification of Contaminated Sites Using a Fuzzy Rule Based System

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ABSTRACT

This paper presents the general framework of a multi level model to manage contaminated sites that is being developed. A rule based system along with a scoring system for ranking sites for phase 1 ESA is being proposed (Level 1). Level 2, which consists of the recommendation of the consultant based on their phase 1 ESA is reasonably straightforward. Level 3 which consists of classifying sites which already had a phase 2 ESA conducted on them will involve a multi-objective decision making tool. Fuzzy set theory, which includes the concept of membership functions, was adjudged as the best way to deal with uncertain and non-random information.

INTRODUCTION

Management of contaminated sites is a major issue for many environmental engineers and other professionals. This is especially so if the corporation is large and has quite a few sites. In many large jurisdictions, a manager may be responsible for up to a few hundred potentially contaminated sites. While some of these may be large and well characterized, most others will be small to medium sized with limited information about the level of contaminant and the extent of contaminating activity conducted on site. Quite often, prior to a phase I Environmental Site Assessment (ESA), the managers have very limited knowledge about the site and they have to decide based on the sparse information whether a phase I ESA is even necessary. In such situations, one needs a decision system to screen and prioritize the sites. It is necessary to have a consistent system to screen sites so that the individual biases of the person screening the sites do not play a role. Such a system then becomes defensible to senior administrators and auditors. While a perfect screening system is desirable, it can only be achieved as it evolves in this direction as more sites are screened and new information is processed. Due to the large number of sites that may eventually need a phase I ESA, even those sites that need a Phase I ESA may have to be prioritized, so that those with higher potential risk get the immediate attention.

The outcome of a phase 1 investigation, determines whether an intrusive phase 2 ESA is necessary. If the phase 2 investigation is deemed "not necessary" then no further action is taken. Otherwise a detailed phase 2 investigation with sample collection and analysis is pursued. This leads to identification of contaminated areas and levels and types of contamination. Once the phase 2 investigation is concluded and the level of contamination is established then the managers have to decide how to further "manage" the site. Questions such as whether a site needs remediation and if so when to initiate remediation need answers. This would depend on the health and ecological risk posed by the site, how far the contamination is from the property line, the cost associated with its remediation and others. A detailed health and ecological risk assessment is a comprehensive task with significant costs and can not be conducted on all sites. The outcome of each phase 2 investigation is unique and while some may indicate contamination levels, which have significant health and ecological impacts, there may be others with less severe levels of contamination. If a site needs remediation, then the managers are faced with a further question as to how to prioritize their remediation with the limited resources available.

This paper discusses the framework of a model that is being developed to aid the managers through this complex maze of decision-making. The first part of the model deals with rules to identify sites that need a phase I ESA and then to prioritize these sites for phase I ESA based on the sparse information available for the sites. The second part of the model, which is still under development, deals with site management once the phase 2 ESA is conducted.

MODEL FRAMEWORK

Fig. 1. provides the framework of the model, being developed. The model has three levels. Level 1 deals with initial site screening for phase 1 ESA. Level 2 deals with those sites on which a Phase 1 ESA has been conducted and Level 3 deals with sites on which a Phase 2 ESA has been conducted (see Fig. 1.).

Level 1: This is the initial screening process. Once a site has been acquired, a decision has to be made whether the site warrants a phase 1 ESA. At this stage, a rule-based system is used to classify the sites. The following three classes have been defined:

Class 1: action needed –A phase 1 ESA is recommended for these sites

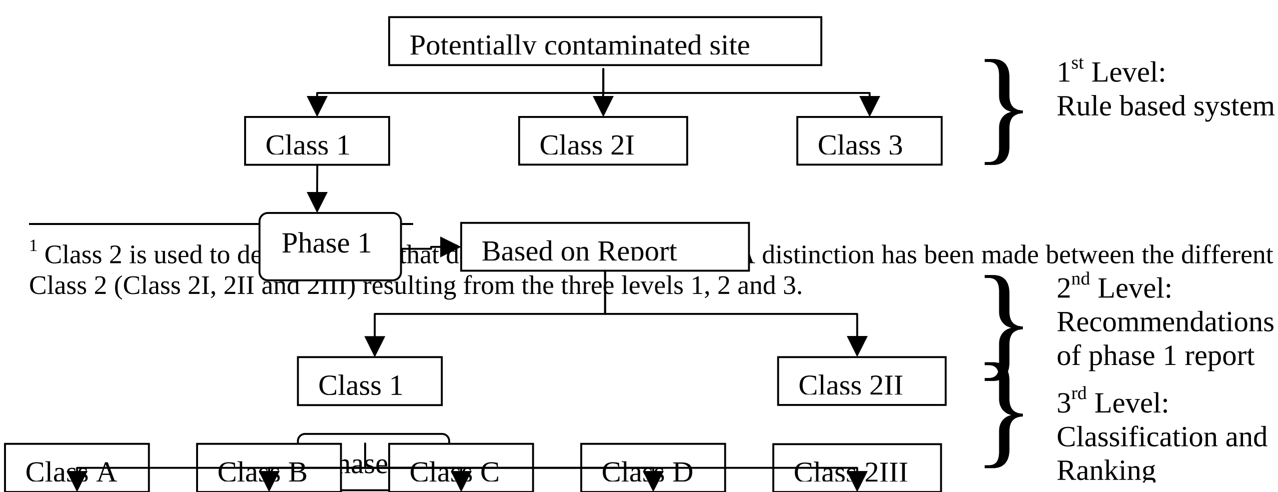
Class 2[1]- Need no further action – If new information about these sites becomes available they will have to be reassessed.

Class 3- See reports – These are sites that already have more information about them in previous environmental reports and these should be consulted. Based on the information in the reports the sites can be classified as class 1 or 2. Sometimes, there may not be a report for a particular site but there may be an environmental report for an adjacent site, which can be consulted for the classification.

Level 2: This level pertains to sites on which a phase 1 ESA has already been conducted. The consultant's phase 1 site investigation report provides a recommendation whether a phase 2 is warranted. At this level the sites are classified, based on the consultant's recommendation, as those for which a phase 2 is to be conducted and those for which no further action is needed.

Level 3: This level deals with sites on which phase 2 site investigations have already been conducted and details of level and extent of contamination are available. These sites have to be classified as:

Class A: Need immediate remediation and/or management.



[1] Class 2 is used to de[illegible] that d[illegible] distinction has been made between the different Class 2 (Class 2I, 2II and 2III) resulting from the three levels 1, 2 and 3.

Class B: Need remediation and/or management but can wait for a few years.
Class C: Do not need remediation, need long term monitoring (Risk Managed sites).
Class D: Low risk, do not need remediation, need intermittent monitoring.

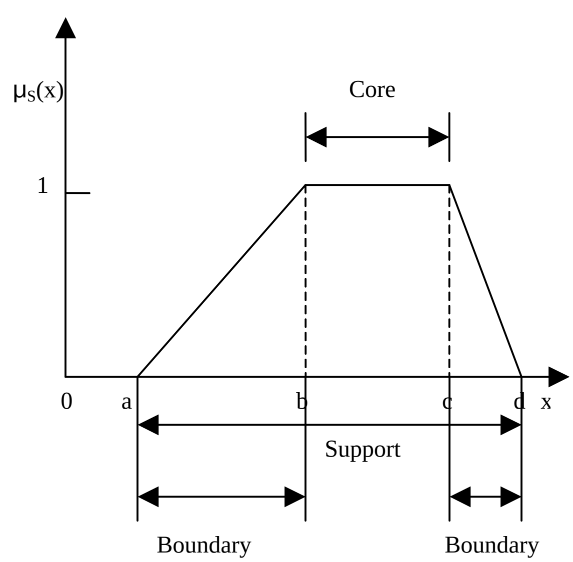
Fig. 1. Model framework

Class 2 III: No further investigation is needed at this time

For this level, a fuzzy multi-objective decision making (MODM) model is being envisaged. It will take into consideration site-specific issues, the human health and ecological impacts of a site; the cost associated with remediation and/or monitoring as well as legislative compliance issues. The model is expected to be a dynamic system and the site classification can change as further site-specific information is obtained. There is usually some uncertainty in the site information. The field data are spot measurements in time and space and these are extrapolated to develop contours and fence diagrams. In addition, often the measurements are "eye-balled" or may be linguistic such as "high", "medium" or "low", "near" or "far" and so on. The larger sites, on which phase 2 ESAs have already been conducted, are usually better characterized (there may be some vagueness in these as well), than the smaller ones. As there are significant uncertainties in site information the application of fuzzy logic is considered most apt.

FUZZY LOGIC AND MEMBERSHIP FUNCTIONS

Fuzzy logic is a multi-valued logic system that has been used for non-random uncertainty analysis. Elements in fuzzy sets have memberships that vary in the interval between 0 and 1, zero being no membership and one being full membership (Ross, 2004). While, in the binary world, elements either belong or do not belong to a particular set (membership 0 or 1), in a fuzzy set, an element can have a partial membership. Membership of an element x in a fuzzy set S is represented as $\mu_S(x)$. A fuzzy set is described by its membership function, which is comprised of



core, boundaries and support. A convex fuzzy set is shown in Fig. 2.

Fig. 2. Features of a fuzzy set

The membership value of x in this set can be denoted as (Seo, et al.2003):

$$\mu_s(x) = \begin{cases} \dfrac{(x-a)}{(b-a)}, & \mathrm{a} \le \mathrm{x} \le \mathrm{b} \\ 1 & \mathrm{b} \le \mathrm{x} \le \mathrm{c} \\ \dfrac{(d-x)}{(d-c)}, & \mathrm{c} \le \mathrm{x} \le \mathrm{d} \\ 0 & \mathrm{x} > \mathrm{d} \text{ or } \mathrm{x} < \mathrm{a} \end{cases} \qquad \text{(Eq. 1)}$$

Rule Based Systems

A rule-based system is a non-linear mapping of input to output in cases where no mathematical relationships exist or mathematical relationships are too complex to develop (Ross, 2004). It is expressed in a linguistic form as:

IF premise (antecedent), *THEN* conclusion (consequence) (Eq. 2)

A fuzzy rules-based system is a set of rules with input variables in the form of fuzzy sets with membership functions and a set of consequences also in the form of a fuzzy set.

LEVEL 1: DECISION RULES FOR CLASSIFYING SITES

The following decision rules were developed for classifying the sites. These are:

Rule 1: IF there is an environmental report for the site or for an adjacent site (within 100m) then Class 3

Rule 2: IF a review of past reports (once the site has been classified as Class 3) show no concern then Class 2

Rule 3: IF the area is < 0.05 acre then Class 2

Rule 4: IF there is no source of contamination on site or within 100m then Class 2

Rule 5: IF there are petroleum or chemical storage tanks on site, then Class 1

Rule 6: IF there is potential contaminating activity (PCA) on site or within a 100m radius then Class 1

Rule 7: IF there is a landfill on-site or within a 40m radius then Class 1

Rule 8: IF there is a Foreign Utility Well on site Then Class 1

Rule 9: IF there is a Foreign Utility Pipeline on site Then Class 1

Precedence of Rules

In a system like this, one needs a precedence of rules, which ones come first and which ones come later. The rules have been numbered according to their precedence. Thus, if a site (or one from an adjacent site) has an environmental report then it is important that it be consulted before a decision is made. Similarly, if a site does not have an environmental report but has a very small area (<0.05 acre) then it can be parked as "Class 2", with no further action. Sites, which do not fall under the purview of class 3 or 2 are automatically class 1. Even within class 1, more information on the site such as "potential contaminating activity (PCA)" or a "foreign utility line" on site, would help the manager prioritize the sites for phase 1 ESAs. Thus, the model provides two outputs for each site: (a) the class (b) the site characteristic that places it in that class. Thus, the manager would know that a particular site is say "Class 2" and "area<0.05 acre". Sites, which are classified as "Class 1" and yet do not fire any of the other rules (rule 5-9) are labeled "default".

Scoring System

Once the sites are classified, a scoring system is used to rank the sites within class 1 based on its characteristics, geology, hydrology, hydrogeology, land use, receptor and pathways for contamination.

A total of 100 points are assigned to the main factors that have major impact on the safety of the site regarding human population and environment, and are distributed amongst these factors according to their relative importance. The major aspects of the scores of a site are hazard and sources of contamination, exposure pathways and effects of exposure on the receptors. The scoring system generally follows the Canadian Council of Ministers for the Environment (CCME) National Classification System for Contaminated Sites. The scoring system would also consider information within a 100 m radius of the site. For example, if there is no source on-site, but there is a source within 100m from the site, then a score that is prorated to the distance of the contaminant source will be considered.

An ideal score assignment should be able to represent the exact situation observed by the site engineer and transmit it to the decision-makers without loss of information. Unfortunately the lack of data, subjective interpretation of data and differences of data quality from one site to another, is not easily represented by a system of deterministic scores. Ideally, one would like to consider the site engineer's linguistic expressions to describe sites conditions, such as distance from the nearest potential contaminating activity as "very near" or "far". It may be possible to represent some of this information as fuzzy inputs in order to develop a better numerical ranking system. These fuzzy input numbers can be added to develop a fuzzy score, which can be used to rank the sites.

LEVEL 2

In Level 2, the consultant’s recommendation based on the findings of the phase 1 ESA will be followed and hence this is relatively straightforward.

LEVEL 3

At this level, classification of sites to prioritize them as A,B,C,D,E and 2III (see above) has to be conducted. This requires a significant amount of site-specific information. However after a phase 2 ESA, much of the information is already available. This pertains to issues such as: land use (residential, parkland, commercial, industrial; in some cases there might be more than one land use; in such cases the most sensitive land use will be considered), site sensitivities (proximity to day care, senior housing, affordable housing, hospitals, schools), potential for groundwater contamination, potential for surface water contamination, potential for airborne contamination, contaminant specific parameters, cost of remediation and others. This stage of the model is currently being developed.

CONCLUSIONS

Management of contaminated sites is a complex task. The uniqueness of each site and the sheer number of sites that managers have to deal with further compound the difficulties in making judicious decisions regarding the management of each site. The framework of a multi-level model to classify and rank the sites is discussed. A rule-based system, is being proposed for the preliminary screening of sites.

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