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ASSESSING, COMPARING AND PRIORITIZING CONTAMINATED SITES: APPLICATION OF A MULTIPLICATIVE RISK ASSESSMENT MODEL

Margaret Allan, M.Eng., P.Eng., P.Geol.[†] and Nicole Ducharme, P.Eng.[†]

Abstract

Evaluating the risk posed by a contaminated site involves assessing hazards, receptors and exposure pathways. Since risk exists only when all three of these components are present, it is advantageous to use a multiplicative model rather than a summative model for assessing risk potential.

Matrix Solutions Inc. developed a spreadsheet model to facilitate comparing contaminated sites on the basis of the risks they pose. Hazard, receptor and exposure pathway scores are developed under a methodological framework that reduces opportunities for judgmental bias. The product of the three scores is used to categorize the risk level and recommend further action. In addition to categorizing risk level, the model tracks uncertainties and identifies input parameters warranting refinement to improve the reliability of the output.

This model has been used to categorize numerous contaminated sites. Three examples are presented and compared, to demonstrate the application and advantages of the multiplicative model. Use of this model is recommended to prioritize a portfolio of a large number of contaminated sites, to ensure that they are managed in an efficient, effective, and environmentally and fiscally responsible manner.

†Matrix Solutions Inc., Calgary, Alberta

1.0 INTRODUCTION

Managers responsible for a portfolio of contaminated sites face the ongoing challenge of allocating limited resources to those sites. Many factors affect which sites receive funding and attention. Some of these factors are legal requirements, economic return, prior commitments, public/stakeholder pressure, and the amount of risk posed by a contaminated site.

The Canadian Council of Ministers of the Environment developed a number of site assessment and management tools under The National Contaminated Sites Remediation Program, which began in 1989. One of these tools was the National Classification System for Contaminated Sites (CCME, 1992), which was developed to screen contaminated sites on the basis of current or potential environmental and human health risks. Over the past decade Matrix Solutions Inc. (Matrix) has used and modified this tool to assist its clients with prioritizing their portfolios of contaminated sites. This paper presents and discusses the most recent modification, which is a multiplicative model for comparing and prioritizing contaminated sites on the basis of current or potential risk.

The multiplicative risk assessment model can be used as a coarse screening tool to help managers sift through a large number of sites and identify those with the greatest potential to impact nearby receptors. Other factors such as regulatory compliance, stakeholder commitments and economics are external to the model but may be deciding factors.

2.0 MODEL FRAMEWORK

Using a model to compare and rank risks at contaminated sites is valuable because it removes some of the subjective bias in decision making by requiring a consistent, methodical evaluation approach that addresses all of the key factors contributing to risk. Users of the model have a defensible basis for assigning priorities.

In classical risk assessment, a risk is manifested when a receptor (human or ecological life form) comes into contact with a hazard (a chemical or contaminant) through one or more exposure pathways (routes of contact). Thus, in the National Classification System for Contaminated Sites (CCME, 1992) and in our risk model for comparing and prioritizing contaminated sites, current or potential risks are scored in three categories: hazards, receptors and exposure pathways.

Over the years, Matrix has developed a number of modifications to the CCME (1992) model to better suit the needs of its clients, many of whom are in the upstream oil and gas industry. The most notable changes are as follows:

- The tool has been developed as a Microsoft Excel® spreadsheet, to automate score calculation, yield a printable summary, and facilitate copying of scores into other applications.

- Specific chemical hazards particular to the upstream oil and gas industry are identified. The key chemical hazards at such sites include petroleum hydrocarbons, salts, metals and naturally occurring radioactive materials (NORMs). These hazards are weighted based on their hazard potential (relative mobility and toxicity).

- Parameters/characteristics that are irrelevant or of minor importance at western Canadian oil and gas sites have been removed.
- Hyperlinks have been added to online sources of input information such as precipitation maps.
- The hazard, receptor and exposure pathway scores are multiplied rather than added.

The last point warrants particular discussion. In the CCME (1992) model, the hazard, receptor and exposure pathway scores have upper bounds of 33, 34 and 33 points, respectively, for a total score out of 100. Although people can readily identify with a 0-100 scale, this approach has a shortcoming: it is possible to have a zero in one of the three areas (which, according to classical risk assessment, implies zero risk) and yield a score greater than 65. To overcome this, Matrix uses hazard, receptor and exposure pathway scores each out of 10 and multiplies them, for a total score out of 1,000.

3.0 SCORING A SITE

In the Matrix model, hazard, receptor and exposure pathway scores are totalled on separate worksheets. Each worksheet identifies the parameters/characteristics being scored and the minimum and maximum number of points that can be assigned to each. There is a space to record the assigned score and another space to comment on the basis for that score. Total scores for the hazard, receptor and exposure pathway worksheets are carried forward to a separate worksheet that assesses the total score and categorizes the apparent risk level.

3.1 Hazard Factors

Factors contributing to the hazard score are grouped into two categories: soil contaminants and water contaminants. The individual parameters/characteristics that are scored are as follows:

H1 — Petroleum hydrocarbon (BTEX and F1-F4) concentrations relative to applicable soil quality criteria

H2 — Salinity (EC) and sodicity (SAR) relative to applicable soil quality criteria

H3 — Acidity/alkalinity (pH) relative to applicable soil quality criteria

H4 — Metals concentrations relative to applicable soil quality criteria

H5 — Naturally occurring radioactive material (NORM) relative to applicable criteria

H6 — Volume of impacted soil

H7 — Special considerations (soil)

H8 — Primary domestic water supply contamination relative to drinking water criteria

H9 — Secondary groundwater supply contamination relative to drinking water criteria

H10 — Surface water contamination relative to usage criteria

H11 — Groundwater quality in groundwater monitoring wells

H12 — Total area with a groundwater plume

H13 — Special considerations (water)

The score for many of the soil and water hazard factors is assessed based on how many times over or under criteria each contaminant is. The applicable criteria are used as the benchmark because this accommodates jurisdictional differences. The "special considerations" hazard factors under the soil and water headings allow the user to adjust scores up or down to take into consideration aspects that the model may not address adequately (particularly high concentrations or naturally high background concentrations, for example).

3.2 Receptor Factors

Factors contributing to the receptor score are grouped into two categories: ecological and human. The individual parameters/characteristics that are scored are as follows:

R1 — Distance to natural area, agricultural land use or residential land use

R2 — Distance to perennial surface water

R3 — Special considerations (ecological)

R4 — Distance to agricultural land use or residential land use

R5 — Distance to commercial land use or industrial land use

R6 — Distance to wellhead (active, suspended or abandoned)

R7 — Distance to nearest domestic water well or spring

R8 — Availability of alternate domestic water supply

R9 — Distance to secondary groundwater user

R10 — Usage of secondary groundwater supply

R11 — Usage of surface water

R12 — Special considerations (human health)

As with hazard factors, "special considerations" allow the user to adjust ecological or human receptor factors up or down to accommodate sites where the receptors are of particular importance (such as a town water well) or of lesser concern (for instance if administrative controls prohibit water usage).

The distance to a wellhead affords the site owner a small degree of protection because of site development restrictions near active or abandoned wells.

3.3 Exposure Pathway Factors

Factors contributing to the exposure pathway score are grouped into two categories: subsurface transport and surficial transport. The individual parameters/characteristics that are scored are as follows:

E1 — Hydraulic conductivity of the site soils

E2 — Range of average yield of wells in the aquifer(s) of concern

E3 — Thickness of confining layer over the aquifer(s) of concern

E4 — Hydraulic conductivity of the confining layer

E5 — Annual rainfall

E6 — Special considerations (subsurface)

E7 — Topography

E8 — Vegetative cover

E9 — Surface water controls

E10 — Runoff potential (precipitation component)

E11 — Runoff potential (infiltration component)

E12 — Flood potential

E13 — Special considerations (surficial)

As with hazard and receptor factors, "special considerations" allow the user to adjust subsurface or surficial exposure pathway factors up or down to accommodate aspects that the model may not address adequately (the presence of fractured bedrock or a hydraulic barrier, for example).

4.0 UNCERTAINTY ASSESSMENT

Rarely will complete information, backed up by testing and analysis, be available for all sites in a portfolio. Therefore, the user will often have to depend on "best guesses" for a number of the factors to be scored. To accommodate this, Matrix built uncertainty assessment into the model to track confidence in the input scores and evaluate the effect of the uncertainties on the overall site score.

For each parameter/characteristic to be scored, the user enters a number between 0 and 1 to indicate confidence in the score assigned. A 1 indicates complete confidence (for example, hydraulic conductivity measurements at a number of onsite wells) whereas a 0 indicates complete uncertainty (there are no data to support selection of the assigned score).

The influence each uncertain parameter/characteristic has on the overall site score is assessed mathematically. Because of the multiplicative formula used to calculate the total site score (hazard × receptor × exposure pathway), a hazard factor becomes amplified by the product of the total receptor score and the total exposure pathway score. This can be used to determine the impact of that particular hazard factor on the total score and the relative importance of the uncertainty attached to that hazard factor. When the analysis is done for all 38 parameters/characteristics, a sensitivity-weighted confidence score can be assigned and the most influential uncertainties flagged to indicate which parameters/characteristics most warrant investigation or testing to improve confidence in the overall site score.

5.0 RISK CATEGORIES AND APPROPRIATE ACTIONS

The combination of total risk score and overall confidence score is used to categorize the apparent level of risk at a site. Appropriate strategies for that site are dependent on the risk category.

The five risk categories and corresponding strategies are as follows:

A – risk >250 and confidence >80

- Develop and implement remediation plans.
- Consider hazard, receptor and exposure pathway risk factors and propose an action that will adequately reduce risk.
- Conduct a site-specific risk assessment.

B – risk >250 and confidence 60-80 OR risk 100-250 and confidence >80

- Consider hazard, receptor and exposure pathway risk factors and propose an action that will adequately reduce risk.
- Assess remediation options.
- Acquire additional information to improve the confidence score and re-evaluate the risk.
- Consider hazard, receptor and exposure pathway risk factors and develop a monitoring program that will identify when changes occur.

C – risk <250 and confidence 60-80

- Acquire additional information to improve the confidence score and re-evaluate the risk.
- Consider hazard, receptor and exposure pathway risk factors and develop a monitoring program that will identify when changes occur.

D – risk <100 and confidence >80

- Schedule re-evaluation of risk in two years or when a known change occurs.

N – confidence <60 (regardless of risk)

- Acquire additional information to improve the confidence score and re-evaluate the risk.

6.0 CASE STUDIES

Matrix has used its multiplicative comparative risk assessment model to rank and prioritize numerous sites for its clients. The following three examples demonstrate the usefulness of the hazard, receptor and exposure pathway scores for categorizing the level of risk at a site and establishing the most appropriate courses of action.

6.1 Case 1 – Free Product at a Gas Processing Plant

This site is located in rural south-central Alberta and consists of a sweet gas plant that has been in operation for more than 40 years. The facility includes process and office buildings, propane bullets, aboveground storage tanks, surface water collection ponds, a flare stack and an inactive flare pit. It should be noted that the original flare pit is unlined, has not been removed, and was in use from 1965 to 1997. The surrounding land use is agricultural.

The current monitoring well network for the site consists of 72 wells, and indicates the presence of a condensate plume that spans an area greater than 135,000 m^2. Free product has been encountered in more than one-third of the monitoring wells.

The surrounding topography is rolling to hummocky with a steep slope to the southwest of the site. An intermittent creek is located approximately 250 m south of the site, which drains to the south-south west. In the impacted area of the site, the geology generally consists of 2 to 4 m of till underlain by fractured sedimentary bedrock (of the Paskapoo Formation, the major bedrock aquifer in the area). Groundwater flow is radial beneath the site, with a strong southerly component of flow. More than two dozen residential water wells were field-verified within a 1.5 km radius of the gas plant, with the closest domestic-use water well located approximately 0.6 km south of the gas plant.

The Matrix risk assessment model was utilized to categorize the level of risk for the site, and the results are summarized as follows:

Risk Category:	**A**
Confidence Score:	**92 out of 100**
Total Risk Score:	**443 out of 1,000**
Hazard Score:	8.10 out of 10
Receptor Score:	7.30 out of 10
Exposure Pathway Score:	7.50 out of 10

Because of factors including concentrations of dissolved-phase hydrocarbons relative to soil and groundwater criteria, the areal extent of soil and groundwater impact, the proximity to both ecological and human receptors (agricultural land and a major domestic-use aquifer) and the occurrence of free product and fractured bedrock (special considerations), this site was assigned a risk score of 443 and a risk category of “A”. Contaminant source removal and the implementation of a remediation plan were strongly recommended.

A multi-phase extraction (MPE) system was recommended and pilot testing has been completed to support full-scale design and implementation.

6.2 Case 2 – Produced Water Spills in Southeastern Saskatchewan

This site is located in rural southeastern Saskatchewan and consists of a collection of active well sites and two former single-well batteries that encompass an area of over

100 ha. The oilfield facilities are situated within agricultural land that is currently used by the landowner for livestock grazing. The landowner's residence is situated approximately 100 m from the site.

The results of electromagnetic (EM) surveys, borehole drilling and monitoring well installations (51 wells) indicate that historical produced water releases from the batteries have adversely affected soil and groundwater quality in an area of land measuring approximately 20 ha.

The topography of the site slopes gently to the east at a 1% gradient and is interspersed with low relief hummocks with small wetlands established in most depressions. The closest major water bodies are a creek which is situated approximately 1.5 km east of the site, and a lake which is situated approximately 2 km west of the site. A large slough, used by the landowner for livestock watering, abuts a portion of the site to the north.

In the area of impact, the geology generally consists of unconsolidated sediments comprising an upper sand and gravel unit underlain by a clayey, silty, sand till unit with channel sands present at some locations. The channel sands, when present, are generally found at depths ranging between 3 and 7 m below ground surface. Groundwater flow is directed toward the east-northeast, in the direction of topographic slope. The landowner's livestock well is shallow (approximately 7 m deep) and is situated less than 200 m downgradient of the eastern limit of the site.

The Matrix risk assessment model was utilized to categorize the level of risk for the site, and the results are summarized as follows:

Risk Category:	**A**
Confidence Score:	**94 out of 100**
Total Risk Score:	**281 out of 1,000**
Hazard Score:	5.60 out of 10
Receptor Score:	8.00 out of 10
Exposure Pathway Score:	6.28 out of 10

Because of factors including EC values relative to soil and groundwater criteria, the areal extent of soil and groundwater impact, proximity of the site to both ecological and human receptors (agricultural land use, perennial surface water, and a residential well) and the hydraulic conductivity of the soils, the site was assigned a risk score of 281 and a risk category of "A". The implementation of a remediation plan is strongly recommended.

A soil and groundwater remediation system comprising a tile drainage system with continuous groundwater recovery was implemented at the site.

6.3 Case 3 – Road Salt at a Former Road Maintenance Yard

This site is located within the municipal limits of a major Alberta city. Former facilities included an office trailer, a maintenance shed, a salt storage tent, an earthen dugout for collection of surface water, an equipment storage area, stockpiles of calcium-treated sand and gravel, a pickled sand pile and road gravel.

The results of EM surveys, borehole drilling and monitoring well installations (31 wells) indicate that sodium chloride has adversely affected soil, groundwater and surface water quality both on- and off-site.

Surrounding land use includes a residential subdivision, pasture and a divided highway. A pasture and intermittent pond area are present within the median of the highway, and a permanent pond surrounded by agricultural land is present on the other side of the divided highway. Surface drainage is directed into an on-site dugout. When full, this dugout discharges to a ditch and culvert system that ultimately discharges into the permanent pond.

The site geology generally consists of a thick sequence of glacial till sediments overlying bedrock. The hydraulic conductivity of the till is very low, ranging from 10^{-10} to 10^{-8} m/s. Discontinuous sand and/or gravel lenses are present in the till. Residents of the neighbouring community obtain their water supply from a municipal water source; however, two domestic-use water wells are located 0.9 km from the site.

The Matrix risk assessment model was utilized to categorize the level of risk for the site, and the results are summarized as follows:

Risk Category:	**D**
Confidence Score:	**92 out of 100**
Total Risk Score:	**82 out of 1,000**
Hazard Score:	3.80 out of 10
Receptor Score:	6.50 out of 10
Exposure Pathway Score:	3.30 out of 10

Because the soil is of low hydraulic conductivity and chloride and EC are the only parameters exceeding criteria, the site was assigned a risk score of 82 and a risk category of “D” despite the proximity to human and ecological receptors. Hence, no immediate course of action was warranted other than re-evaluating risks every two years or when a known change occurs.

Despite a “D” risk evaluation rating, a remediation plan was implemented at the site at the request of the owner due to perceived receptor sensitivity and considerations other than risk (such as politics and compliance with the owner’s environmental policies). The remediation plan included selected source removal, installing an engineered barrier, and continued groundwater monitoring.

7.0 CONCLUSIONS

The comparative risk evaluation model aids non-subjective and defensible prioritization of contaminated sites. In combination with other factors, it helps decision makers determine where best to allocate limited financial resources.

8.0 REFERENCES

Canadian Council of Ministers of the Environment (CCME), 1992. National Classification System for Contaminated Sites. National Contaminated Sites Remediation Program report CCME EPC-CS39E. Winnipeg, Manitoba, March 1992.