Risk Assessment of Contaminated Sites: a Proper Screening Methodology for Sustainable Policies?

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Abstract - In this paper, different contaminated sites' risk assessment approaches are considered, compared, and their suitability to support sustainable policies discussed using a case study.

Key Words: Contaminated sites, risk assessment, benchmarking, pollutants exposure, sustainable policy.

1 Introduction

The main purpose of current legislation concerning the remediation of contaminated sites is to protect public health and, at the same time, the environment. The main approach consists in establishing "limit values" for key environmental quality parameters, and in comparing these with the actual values observed on site; a site is by definition considered "polluted" when observed values exceed the limits. As there cannot be sufficient funds available to address all the sites that may thus result polluted, further conditions apply before actual intervention can be justified and implemented. This consists in carrying out a "relative" risk analysis, that is, a ranking among different polluted sites by means of a score system that should allow to prioritize interventions, based on the degree of potential risk to public health. Usually this approach does not take into account the financial return of the investment for remediation in terms of either added health protection or use value of the decontaminated site. The third step is to carry out an "absolute" risk analysis, which is used to establish the degree of remediation necessary in order to accept the resulting residual risk. In this type of approach, the final use of the once-decontaminated site is already decided, and this should somehow be taken in to account, as a financial return, in the decision process (but it seldom is).

In this paper, the third level of approach is considered, that is, a contaminated site (kept anonymous upon request of the agency in charge) was subjected to an "absolute risk assessment" procedure. An "absolute risk assessment" procedure evaluates the risk on human health of a contaminated site (EPA, 1989; EPA, 1991) and can be used to precisely define the remediation objectives of that site in view of the residual risk after the intervention (UNICHIM, 1997).

2 Methods

The phases, or steps, of a risk assessment procedure are the following:

1. *Data gathering and evaluation*. Conceptual model of the site, identification of: pollution source, pollutants pathways, receptors (humans and/or environment). If even one of the above components cannot be identified, then risk is non existent.
2. *Toxicological evaluation*. Potential effects of the substances evaluated for toxic and/or carcinogenic effects, using appropriate data bases (e.g. IRIS from the US EPA).
3. *Exposure evaluation*. Evaluate receptor's exposure to the potentially harmful substances, taking into account all present, future and possible exposure pathways.
4. *Risk assessment and characterisation*. Evaluate actual risk to receptors: for purely toxic substances as ratio between pollutant intake and related *RfD* (Reference Dose), for carcinogenic substances as CDI (Chronic Daily Intake) and related *SF* (Slope Factor).

The above steps can be followed in "reversed" order, in order to determine which are the "residual" concentrations that will originate an acceptable level of risk. Usually, it is technically unfeasible, and economically unthinkable, to reach a "zero" residual risk, therefore a "reverse" risk analysis has the purpose to determine those site conditions that can be considered "safe" for human health and for the environment. Although the concept of "acceptable risk" could be subject to

severe criticism, as general guidelines the following values could be considered:
- for carcinogenic compounds, a risk of 10^{-6} (U.S. EPA) or 10^{-5} (WHO);
- for toxic compounds, a total HI (Hazard Index) < 1.

Phases 1-3 above are conducted by specialists based equally on existing protocols and personal experience; the latter phase is usually carried out by "models" expressely prepared by sectoral agencies. These are usually "closed" models, in the sense that once phases 1-3 are completed, the experience of the expert falls in the background, as the inner algorithms of the model depend solely on the predetermined input. In this paper, three such models are "benchmarked" against the same real site contamination case study; these are:
- ROME (ReasOnable Maximum Exposure), developed by the Italian ANPA (National Agency for Environmental Protection);
- RISC (RISk-Integrated Program for Cleanups), developed by British Petroleum
- UMS (Umwelt-und-Mensch mit Schadstoffen), developed by the German Federal Environmental Protection Agency.

These three models, implemented in computer programs distributed either freely or commercially, respond to different originating philosophies and therefore their answers will be evaluated and critically compared.

3 Description of case study

The case study is a former underground oil storage facility in a plain area of Northern Italy. Years ago, during plant closure, it was discovered that in, time large, quantities of hydrocarbons had spilled into the ground. The source of pollution is therefore clearly defined and the pollutants known with a good level of confidence. In order to characterize the area, a grid of 43 cells covering an area of 2.5 ha was drawn and used to conduct the investigation campaign. Compounds were identified at 62 points, for each point at 2 or 3 sampling depths. A grand total of 136 samples were analysed. Contaminants were detected as benzene, toluene, ethylbenzene, xylene, ether, in addition to other hydrocarbons in lesser quantities. Table 1 summarizes these results. For each substance, the intrinsic risk was also calculated. The results are shown in Table 2. Total risk for carcinogenic substances was determined as R=0.209, for toxic substances as R=608,6.

Table 1. Results of the sampling campaign

Compound	Positive samples (n)	Frequency	Max. Observed concentration (mg/kg)	Limit value* (D.M. 471/99) (mg/kg)
Benzene	26	0.19	3.8	0.1
Toluene	48	0.36	29.5	0.5
Ethylbenzene	45	0.33	5.3	0.5
Xylene	50	0.37	26.2	0.5
Ether	37	0.27	79	N/A

* these limits are those specified for green/residential areas

Table 2. Calculation of the intrinsic risk for each of the substances in Table 1

Compound	RfD (mg/kg/d) ingestion| inhalat.		Sf (mg/kg/d)	Ri = Ci x Ti*
Benzene	-	-	1.5-5.5 • 10^{-2}	0.209
Toluene	0.2	0.114	-	147.5
Ethylbenezene	0.1	0.286	-	53
Xylene	2		-	13.1
Ether	0.2		-	395

*Ti (toxicity value for the substance is equal to: *Sf* for carcinogenic and *1/RfD* for toxic substances)

3.1 Conceptual Model of the Case Study

The area surrounding the site is devoted to agricultural uses, and it was assumed that this type of land use will remain unmodified in the future. Examination of the local hydrographic network and the prevalent direction of the hydrogeological flow, it can be safely hypothesised that potentially affected areas are only constituted by the agricultural activities that use water from an irrigation canal flowing nearby the spill area and from irrigation wells (outside the spill area). Hydrogeological investigations have in fact shown two aquifers: one, with base at around 30 m from the land surface and a confined one, about 20 m deeper. The free surface of the first aquifer can be found at a depth between 0.6 and 5.6 m below field level. The deeper aquifer is confined by a completely impermeable layer, and can therefore be considered out of reach of pollution.

The pathways of contamination vary as a function of possible targets and conceptual scenaria. Among the possible ones are:

a. airborne contaminant migration;
b. direct contact with contaminated soil;
c. contaminant migration through groundwater;
d. direct contact with contaminated surface water, after contact with groundwater;
e. ingestion of contaminated fish/agricultural products.

Targets of the contamination can therefore be identified as:
- the consumers of fish/agricultural products (pathways c, e);
- citizens (adults and children) using the nearby canal for recreation (pathways d, e);

- workers involved in the remediation (pathways a, b).

Farmers in the area were ruled out as targets, since the type of pollution and the agricultural practices exclude direct and/or indirect contact between farmers and pollutants.

3.1 Models Benchmarking

The first scope of the work herein presented was to compare (or "benchmark") the answers, in terms of "Risk" and "Level of Remediation" that the three mainstream models (RISC, ROME, UMS) would give when applied to the same conceptual model of a site.

The first application of this analysis was independent for each model, that is, known parameters for the site were introduced in the model, keeping "second level" parameters and coefficients equal to their original "default" values (corresponding to what a "low-to-medium experience" user will end up doing). Subsequently, a second application was conducted with the purpose of understanding those elements that have a greater influence on the final result, trying to obtain similar responses from the different models (use by "experienced" user).

It should be specified that, among the considered models, RISC (British Petroleum, 1997) and ROME (ANPA, 1999) follow closely ASTM (1995, 1998) and EPA guidelines, while UMS, although following that standard, differs slightly from that scheme.

3.1.1 RISC

The model allows "direct" and "inverse" logical flux. In the first case, the "risk" deriving from the contamination is calculated, in the latter, given the allowable risk, acceptable concentrations can be calculated by performing the procedure backwards.

The model cannot expressely consider ingestion of contaminated agricultural products; furthermore, concentration in the canal was assumed equal to concentration in a well. RISC allows at most two simultaneous targets to be considered, therefore two simulations were conducted, the first considering adults and childrens using the canal for recreation, the second considering workers employed in the remediation. The option for worst case (without considering attenuation effects and degradation in time of chemicals) was selected. Running the models in "inverse mode" the remediation objectives can be obtained for the two targets. Results are summarized in Table 3, considering the worst scenario of both cases. It can be seen that the surface water compartment is the most critical one.

Table 3. Remediation levels calculated using "RISC" max. allowable concentrations*

Substance	Soil (mg/kg)	Unsaturated area (mg/kg)	Surf. Water (mg/l)
Benzene	6.89	3.8	$1.05 \cdot 10^{-6}$
Toluene	54.4	**29**	$8.2 \cdot 10^{-6}$
Ethylbenzene	9.61	5.3	$1.5 \cdot 10^{-6}$
Xylene	**47.1**	**26.2**	$7.51 \cdot 10^{-6}$
Ether	143	79	$2.25 \cdot 10^{-5}$

* values in **bold** are lower than maximum observed values

3.1.2 ROME

ROME's structure is very similar to Risc's, the main difference being that concentration limits are provided by Italian Law (D.M. 471/99) are pre-programmed into the structure of the model. Thus, for example, Total Petroleum Hydrocarbons (TPH's) are considered by the model as one of the toxic substance categories. ROME does not allow to simulate dermal contact with surface waters, consumption of agricultural products is not considered, but environmental compartments' risk can be calculated, and thus the risk relative to the most sensitive compartment (groundwater) can be determined. The only "not acceptable" risk in this case was the one posed by the "total Hydrocarbons" group (not considered by "Risc" as such).

Remediation objectives are determined as shown in Table 4. It should be noted that values for groundwater are not the outcome from the inverse calculations, but are plainly taken from the limits set by Italian law.

3.1.3 UMS

UMS stands apart from the two other models herein analyzed: it is a model for the sole calculation of risk, and does not include a transport model. This, called SISIM (Sickerwassersimulation) is enclosed in the UMS package as a stand-alone model operating at a much higher degree of detail and complexity than those embedded in RISCand ROME. Since the necessary data to run this transport model were not available, it was decided to skip this step altogether. Therefore, in this application the observed values will be entered in UMS with the result that transport and dispersion/degradation of contaminants will be neglected, giving origin to a very conservative scenario. In this case it will not be possible to determine remediation objectives.

The results are exposed in Table 5, considering only the cases in which potential problems are evidentiated by the calculation. Two values are reported: ΣRV (the sum of the individual risks from all uptake pathways) and BER (Background Excession Rate): ΣRV<1 indicates a risk that can be ignored, while ΣRV>10 indicates significant risk; BER<1.1 indicates prevalent risk deriving from background conditions, while BER>1.1 indicates risk deriving from the site itself. The interpretation of the results is as follows: both for benzene and ether, there is a risk from ingestion of contaminated products deriving from the contamination occurred at the site that cannot be ruled out, although it cannot be considered significant.

Table 4. Remediation levels calculated using "ROME" max. allowable concentrations*

Substance	Superficial soil (mg/kg)	Deep Soil (mg/kg)	Ground Water (mg/l)
Benzene	**0.6**	**0.6**	0.01
Toluene	**1.25**	**1.25**	0.01
Ethylbenzene	**1.79**	**1.79**	0.01
Xylene	**1.72**	**1.72**	0.01
TPH	25.7	25.7	0.01

* values in **bold** are <u>lower</u> than maximum observed values

Table 5. Results of the simulation done with UMS

Carcinogenic substances: Benzene			
Target	*Pathway*	*ΣRV*	*BER*
Children	Ingestion ("garden")	6.96	31.8 > 1.1
Toxic substances: Ether			
Target	*Pathway*	*ΣRV*	*BER*
Children	Ingestion ("garden")	5.15	5.24 > 1.1

Table 6 summarizes the results obtained in the base simulation: it can be seen that ROME and RISC (the two models that are almost directly comparable) differ in the estimation of the site's maximum risk by an order of magnitude for carcinogens and four (4) orders of magnitude for toxics (this is given by the TPH's in ROME, that are not considered as a group in Risc). UMS only indicates "not negligible" risk from the site.

Table 6. Summary of maximum risk estimates in the base simulation

Model analyzed	*Risk (carcinogens)**	*HI**
Risc	**$8.96 \cdot 10^{-6}$**	<< 1
ROME	$6.71 \cdot 10^{-7}$	**135.4**
UMS	6.96	

* **bold** = not acceptable

Table 7 summarizes the remediation objectives calculated by the first two models in order to reach a carcinogenic risk of less than 10^{-6} and a toxic risk HI < 1 using an inverse logical flux. It can be seen that ROME indicates concentrations that are one order of magnitude lower than Risc, except for the surface water/groundwater compartment. The reason lays mainly in the equation used within the transport modules of each model.

Table 7. Remediation objectives calculated by RISC and ROME

Compartment	Limit concentrations* (mg/kg)									
	benzene		toluene		ethylbenzene		Xylene		ether	TPH
	ROME	Risc	ROME	Risc	ROME	Risc	ROME	Risc	Risc	ROME
Upper soil	**0.6**	6.89	**1.25**	54.4	**1.79**	9.61	**1.72**	47.1	143	25.7
Deep soil	**0.6**	3.8	**1.25**	**29**	**1.79**	5.3	**1.72**	26.2	79	25.7
Water	0.01	$1.05\ 10^{-6}$	0.01	$8.2\ 10^{-6}$	0.01	$1.5\ 10^{-6}$	0.01	$7.51\ 10^{-6}$	$2.25\ 10^{-5}$	0.01

* values in **bold** are <u>lower</u> than maximum observed values

4 Comparative Application

This application was conducted after examining the "inner" structure of each model. In order to standardize the results of the different models, two pollutants (ether and TPH's) were eliminated from those considered in the previous simulation (the model's databases were not modifiable), and only the exposition pathways common to all three models were considered, modifying accordingly the "conceptual model". These are:

- outdoor inhalation
- dermal contact with surface soil
- soil ingestion.

The target groups were also modified, in order to use uniform descriptive, absorption, and exposition frequency parameters. This was particularly critical in UMS, since this model considers five age classes for target groups.

The final results for this series of simulations are shown in Table 8. It can be seen that the toxic risk condition has "disappeared" from the simulation with ROME (this is because TPH's were taken out of the simulation), and that the estimation of total site risk is now "reversed" between RISC and ROME. This could indicate that the two models are more sensitive in different "areas" of risk values (ROME appears to be more sensitive in the low risk area, while RISC in the high risk one). UMS's estimate of risk falls, in this case, below the alert threshold.

Table 8. Results from the comparison application

Model analyzed	*Risk (carcinogens)**	*HI**
RISC	$4.3 \cdot 10^{-7}$	<< 1
ROME	**$5.0 \cdot 10^{-6}$**	<< 1
UMS	<< 1	

* **bold** = not acceptable

Related remediation objectives are shown in Table 9, for the "soil" compartment only. ROME still expresses the most restrictive results and the gap between the output of the two models actually increases (from one to two orders of magnitude).

Table 9. Remediation objectives calculated by RISC and ROME (comparative application)

	Limit concentrations* (mg/kg)							
	benzene		Toluene		ethylbenzene		Xylene	
	ROME	RISC	ROME	RISC	ROME	RISC	ROME	RISC
Soil	**3.13**	7.33	**6.98**	515	**	319	**9.76**	215

*values in **bold** are lower than maximum observed values
** observed value (5.3 mg/kg) does not cause undesirable effects

5 Discussion

The factors that determine the difference in response of the three models herein analyzed are several, and they are also interdependent. While a complete search of these is beyond the scope of this work, some can be pinpointed after the simulations conducted:

- exposure frequencies: these are different (in their default value) from model to model;
- site description parameters: often, the description required by the model is quite rigid and not particularly adaptable (for each model, with different approximations) to the site;
- logic of the programs: logical fluxes and even algorithms (describing the same phenomenon) are different for the different models.

Models may be referred to a specific regulatory condition (e.g. ROME) or biased towards certain types of applicative conditions (e.g. UMS), however the most important point to consider by the modeler is to be aware of the model logic and limitations, in order to understand its results correctly.

The results obtained have relevant consequences in real-life applications. As most regulatory agencies require a “risk assessment procedure” to be conducted prior to the approval of a decontamination project, it is obvious that the process must be conducted and examined with the utmost care. As these procedures are now applied in greater number to contaminated sites it is very important that the application of the model correctly takes into account the underlying hypotheses under which it was originally developed. Most of these models, and certainly ROME and RISC, derive from earlier ASTM work, that was originally carried out for petroleum-contaminated sites and then “freely” extrapolated to all contamination occurrences. Some of the basic assumptions of these two models may therefore not fit completely the reality in which they are often being used. In this respect, UMS seems to be better indicated for a more exact determination of the individuals’ “risk” of exposure, although its application requires a greater effort and more careful initial study.

As mentioned before, however, no one of the examied models pays any attention to the financial aspects (cost/benefit ratio) of the remediation process.

By observing Table 9, it can be seen that ROME estimates, for several compounds, admissible concentrations that are lower than observed values, although the estimated risk, although not acceptable, is marginal.

Without entering in a detailed analysis, that will in any case depend on the specificity of the contaminated site, it can be stated that, by accepting the ROME results acritically, a significant amount of resources will have to be invested in the remediation of the site.

It should be further noted that the methodology calls for possible targets of the contamination, and identification of contamination pathways, without specifying the *probability* of an individual to become a target. In this case, pathways to exposure were discussed in Section 3.1 as part of the conceptual model of the site. Obviously, however, potential pathways will have different influence and significance based on the frequency of actual presence of the final targets. (In a predominantly rural area, targets will likely be present at a lesser frequence than in an urban or industrialized/ commercial area). Since toxicological effects are parametrized based on specified standard durations and frequencies of exposure, a correction factor taking into account the actual presence of the target should help to better represent the needs for public health protection (indirectly, the “cost” to public health of the contaminated site). This factor could be absolute (applied as part of the risk assessment process) or relative (applied in a result cpmarison phase among different sites).

Similar considerations apply to the intrinsic value of the site to be remediated, when remediation funding comes from public agencies. This is usually not a problem with prime sites suitable to residential/industrial redevelopment, as they are usually managed by private companies with a clear concept of financial returns. They however apply to public funded projects or to special cases of authority-mandated, private funded ones.

Remediation is an intervention that makes the site available for its original or foreseen uses within a relatively short period, if compared to naturally occurring remediation processes.

In many cases (e.g. agricultural land that can be pulled out of production or marginal areas that do not need to be readily developed), costs of a delayed availability cane be easily offset by the savings on remediation activities, provided that self-remediation can occurr and no or "low probability" targets are identified.

In these cases, the pure application of a traditional risk assessment methodology alone can mislead the decision-maker into low cost/benefit ratios endeavours. Further constraints on the methodology should be investigated.

6 Conclusions

The conclusion of this work is not, as it could seem, that Risk Analysis is generally unreliable. To the contrary, risk analysis is a very delicate and difficult operation that must be thought out carefully and properly designed in order to be successfully completed.

Risk analysis is not, however, synonymous with the use of risk analysis models such as those that were investigated here. Although these models were created and implemented in computer programs in order to speed up a procedure that may have been too tedious and/or difficult in some cases, their use should not be considered a decision-making tool, but merely a decision-support tool. As it has been shown, the "indiscriminate" use of three models originated quite different answers. If any of them had been actually adopted "as is", the type of intervention and its cost may have been totally different in each case, without the guarantee that the best possible solution had been chosen. Specific provisions for the weighting of the proposed measures' cost-to-benefit ratio in these models should be introduced, especially – but not limited to – in the case of urban contaminated sites, where risk exposure can be significant, and cost recovery is expected to be maximum. In this respect, further research is certainly needed.

A careful and controlled use of these models, under the close supervision of expert technical personnel is therefore recommended solely as a support tool in the risk assessment process of simple site contamination cases; in the most complex cases their use should be substituted by an explicit complete study and modelling procedure conducted solely by expert technical personnel.

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