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THE RISK ASSESSMENT FOR THE MANAGEMENT OF PETROLEUM PRODUCT STORAGE & DISTRIBUTION SITE

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Abstract

The paper presents a risk assessment for the management of contaminated sites. For defining the solutions for management of petroleum products storage and distribution sites there were developed two main activities. The first one consists in a detailed site investigation using a conceptual model to define its geological, hydrogeological characteristics and surely the contamination level. The second activity is dedicated to the assessment of risk generated by the soil, subsoil, air and groundwater contamination, by using a professional software applied to a real case study. The results showed that for carcinogenic and non-carcinogenic compounds the risk is above the thresholds according to the legislation. The conclusions of this analysis allow establishing the measures to mitigate this risk, based on a feasibility study and on the best solutions for site remediation (soil and groundwater).

Key words*: assessment, contaminated, deposits, risk.*

INTRODUCTION

The management of contaminated zones is a tool that prevents and reduces the negative effects generated by these areas to the environment and surely to human health (Bica & Petruta, 2021). Among the analysis criteria used to establish the management solution of a contaminated area must be included two general principles deriving from resource management: minimizing future maintenance needs, respectively regulatory requirements to ensure the safe use of the area and reducing to a reasonable level the constraints of the use of the area (Bica & Petruta, 2021).
For contaminated areas, the risk assessment defines the procedure by which the hazards generated by contamination to the health of the population or to the ecosystem are estimated qualitatively or quantitatively (Bica & Petruta, 2021).
The qualitative assessment of the risk can be subjective, based on the evaluator's experience and with a high degree of generalization.
The quantitative assessment requires a high degree of knowledge of the area, by collecting information from the field, investigations necessary to define the contaminated site.
In the case of quantitative risk assessment numerical data are used and provide the results having an objective character.
In order to perform a quantitative risk assessment, a detailed soil and subsoil investigation plan was prepared of the product storage and distribution site (warehouse), taking into account the potential sources of pollution and define the geological and hydrogeological characteristics of the site, the size of hot spot areas and the specific contaminants.
The lithological section (Figure 1) of the analysed site describes the fact that, down to the depth of approximately 0.7 m, a non-homogenous filling layer develops, consisting of a clayey-sandy layer mixed with sands and gravels (Petruta & Bica, 2021). Under these layers, down to depths of 6.70-7.40 m, a slightly cohesive formation develops, consisting of clayey sandy dusts, plastically consistent (Petruta & Bica, 2021). Starting from depths ranging between 6.70-7.40 m down to depths of 9.30-9.60 m, a non-cohesive formation develops, consisting mainly of wet sands, and down to the depth of 10 m a dusty clay layer, plastically hard, is identified (Petruta & Bica, 2021).

The phreatic aquifer is surrounded by the non-cohesive formation, consisting of sands (Figure 1) and this aquifer is supplied particularly from rainfall and from the nearby river (Petruta & Bica, 2021).

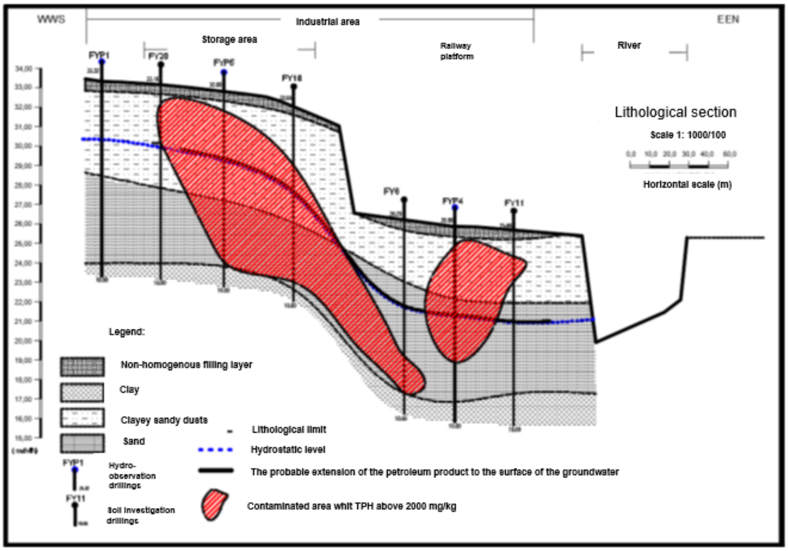


Figure 1. Lithological section

The general flowing direction of the phreatic aquifer is from NV towards SE, more particularly from the monitoring well FYP1, located upstream of the facilities that have a polluting potential, towards the wells FYP2 and FYP3, located downstream of the specified facilities, near the river course (Petruta & Bica, 2021). The phreatic aquifer surrounded by the terrace deposits is supplied from rainfall, whereas the one embedded in the plain is supplied as much from the terrace discharge as from rainfall and from the river (Petruta & Bica, 2021).

MATERIALS AND METHODS

The physical and chemical properties of contaminants was determined with the investigation plan in terms of establishing the sampling points, collecting the samples, and establishing the methods to measure them. Also, these properties control the transport of pollutants into the underground environment, determining the size of the polluted area (Bica, 2014). As regards the types of pollutants specific to the distribution and storage oil industry, it is important to know and assess the characteristics of chemicals, such as: water solubility, density, boiling point, steam pressure, volatilization of pollutants, biodegradability (ARCADIS, 2019).

To assess the degree of horizontal and vertical contamination of the site, 20 soil/subsoil investigation drillings were conducted, out of which 5 drillings (FYP1, FYP2, FYP3, FYP4, FYP5) were turned into hydro-observation drillings to assess the ground water quality evolution in time (Figure 2) (Petruta & Bica, 2021). The drillings were placed in such a way as to cover the entire site, but mainly focalised on the potential pollution sources (judgmental and systematic sampling designs) (Bica, 2014).

Following the investigations and the results of laboratory tests, besides the soil pollution with TPH, soil pollution with aromatic hydrocarbons and concentrations of benzene, respectively, was also identified, which exceed the alert threshold in the drillings made in the tanks park area and the railway platform towards the southern part, FY16 and FY18, as well as the intervention threshold in drillings FYP2, FY7, FY18 (Petruta & Bica, 2021).

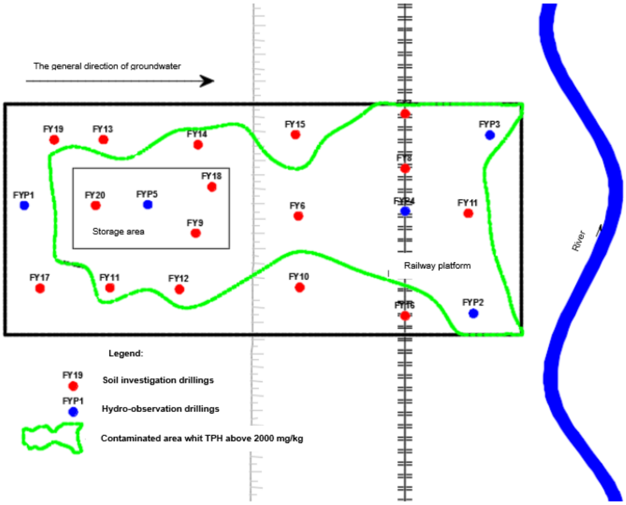


Figure 2. Master plan of the warehouse, with location of technological items

After analysing the laboratory test results and the isolines with the TPH and BTEX (particularly benzene, ethylbenzene and xylene) concentrations, it follows that there is a contamination of the soil, especially at the former facilities: pumping station, tanks and vehicle platform in the northern part of the site, settling tank, the railway platform spot and the scavenge oil storage area (Petruta & Bica, 2021). Following the investigation stage, it was identified a contamination of the soil down to the depth of 4.5-5.0 m and, considering the presence of the hydrostatic level of the underground water at these depths, an active influential and interdependence connection is noticed between soil and groundwater (Petruta & Bica, 2021).

The contamination of the soil on the specific site represents approximately 67% of its total area and the estimated pollution of the groundwater covers approximately 82% of the total specific site (Petruta & Bica, 2021).

Considering the soil permeability, the groundwater was also investigated by using the monitoring wells (Figure 3), following which a significant contamination was noticed (according to Romanian legislation, Ministerial Order no.756/1997 for the approval of the Regulation on the assessment of environmental pollution).

It can be noted that the areas with significant pollution are within the perimeter of the storage tanks, of the petroleum product unloading platform and in the area between the railway platform and the river (Petruta & Bica, 2021).

Significant pollution with petroleum products was confirmed at site level for the aquifer, and such contamination with petroleum products tends to migrate beyond the site.

Considering the detailed investigation stage, the potential exposure pathways taken into account in the quantitative risk assessment are: dermal contact with surface soil during the execution of on-site works; dermal contact with groundwater (thickness NAPLs), this pathway is specific to people who could swim in the river in the immediate vicinity of the site, but this has a low probability of being achieved because the river water is not contaminated in this specific case; soil or water ingestion (accidental); inhalation of particles/dust, on medium and long term exposure route, during the on-site construction works; inhalation of volatile compounds during the on-site works, in which the affected receivers could be the permanent or occasional workers on the site and residents in the proximity of the site (up to 25 m distance), especially in the dominant direction of the wind; solubilization from the soil in the groundwater, considering the results of the water samples.

Also, we mention the fact that both the population and the industrial area do not use the water from the aquifer, there is a centralized

water supply system, so the risk of using underground water is reduced.
Below are presented the measurements performed in the soil drillings and the observation and control drillings (piezometers) with whose help we obtained the input data values of the investigated site.

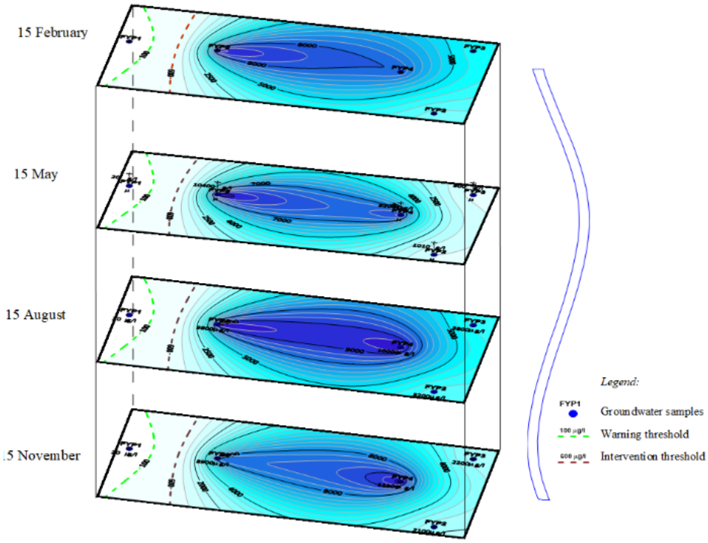


Figure 3. TPH concentrations in the groundwater samples during the monitoring period

The quantitative risk assessment modelling program RBCA Toolkit and RISC5 software were used to run the input data, with the hydraulic gradient value of the water-bearing unit being 0.01.
The thickness of surface soil (outdoor air volatilization factor) zone was set at 1 m and the predominant wind direction is East South - West East and the average annual speed was 2.5 m/s.
The hydraulic conductivity value entered in software is 5.0E-1 (0.5) m/day; the maximum value identified was used, considering it to be the most unfavourable according to the principle of data use.
Effective porosity of the soil varies from 37.5% to 40%. The value of 0.38 was used in the programs.
The flow rate of the aquifer water varies with the hydraulic conductivity; for the risk assessment process, the value of the groundwater velocity was 5.0E-3 m/day. The predominant direction of water flow is West-East, but there are also local variations given by the presence of buildings in the residential area, by the physical characteristics of the soil that drain the water in randomly oriented secondary directions.
The phreatic aquifer is contained in the non-cohesive formation made up of sands. This aquifer is fed mainly by precipitation and by the nearby river. The water level in the site is interdependent with the water level in the river, according to the measurements during the monitoring period of the water level in the monitoring wells.

RESULTS AND DISCUSSIONS

The RBCA Toolkit for Chemical Releases is a comprehensive modelling and risk characterization software package (RBCA Toolkit for Chemical Releases, 2007). The RBCA combines contaminant transport models and risk assessment tools to calculate baseline risk levels and derive risk-based clean-up standards for a full array of soil, groundwater, surface water, and air exposure pathways (Bica & Petruta, 2021).
Similar to the RBCA Toolkit, the RISC 5 software allows determining the values of pollutant concentrations at the source to obtain

a level of risk imposed on receptors; in this way, the remediation levels that should be obtained for the contaminated area are defined.
Similarly, the two RISC 5 and RBCA Toolkit software have the same threshold values, in accordance with international practice and specialized literature; the cancer risk threshold value used will be 10-5, and the threshold value for non-cancer risk will be 1.
The RISC 5 software contains contaminant transport models for estimating their concentrations in various points of contaminated area.
Based on the introduction of the input data, namely the definition of the pollution source, the exposure routes and the way in which the receptors could be affected, the source-path-receptor relationship was defined.
In the first stage, are identified the chemical substances of interest (constituent of concern in each source area, soil and groundwater) and they are chosen according to the database of each program.
The RISC 5 software calculates the risk to human health, separately for the unsaturated zone and groundwater as output data.
In the first part of the software, the conceptual model is defined by choosing the source, respectively the unsaturated zone, this being the main source of contamination on the site (Figure 4).

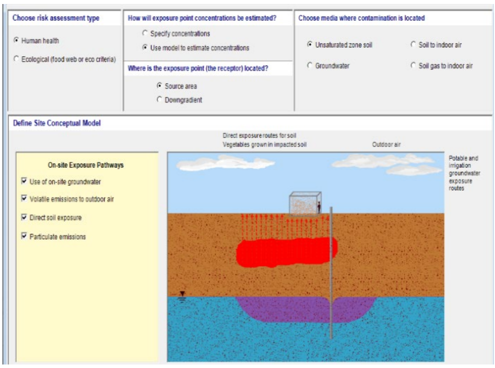


Figure 4. Exposure pathways identified for risk assessment on human health – RISC 5 software

In the following, geological and hydrogeological parameters are characterized, specific pollutants are defined, the contaminated area of the site according to those requested to be completed at the software level and adapted to the real conditions in the specific terrain of the site. Within both programs, RBCA Toolkit and RISC 5, the most unfavourable scenario was considered, having the highest concentrations of pollutants on the entire site.
Considering the input data in the RISC 5 program, the estimated value of the risk on the health of the population (Figure 5) highlights a non-cancerous risk for the soil, as an environmental factor, through the following exposure routes: soil ingestion and dermal contact, in the case of contact with the contaminated soil.

SUMMARY OF HAZARD QUOTIENTS
Receptor 1:
Construction Worker - Upper Percentile

Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Irrigation Water	Dermal Contact with GW	Inhalation of GW Spray	Inhalation of Outdoor Air	Inhalation of Particulates	TOTAL
Benzene	5.9E-02	1.9E-01	0.0E+00	4.5E-31	5.9E-32	4.9E-04	2.6E-15	2.5E-01
Ethylbenzene	1.5E-02	4.8E-02	0.0E+00	0.0E+00	0.0E+00	1.6E-05	4.9E-16	6.3E-02
TPH Aliphatic C10-12	2.4E+00	7.8E+00	0.0E+00	0.0E+00	0.0E+00	5.3E-09	7.8E-14	1.0E+01
Xylenes (total)	1.9E-03	6.0E-03	0.0E+00	0.0E+00	0.0E+00	4.7E-05	1.2E-15	8.0E-03
TOTAL	2.5E+00	8.0E+00	0.0E+00	4.5E-31	5.9E-32	5.6E-04	8.2E-14	1.1E+01

Figure 5. Non-carcinogenic risk assessment in the unsaturated zone - RISC 5 software

Regarding the carcinogenic risk generated by the concentrations of the compounds identified following the site investigation, namely benzene, ethylbenzene, xylene, the risk does not exceed the standardized limit value according to Romanian legislation. The risk generated for contaminated groundwater based on the input data in the RISC 5 program, demonstrates a carcinogenic and non-cancerous risk through exposure to dermal contact with contaminated groundwater (THP concentrations exceed the intervention threshold limit according to the current legislation).
The following figures show some captures from the RBCA Toolkit software used, showing its working mode, respectively the data used for the risk assessment.
Figure 6 shows the identified exposure routes: groundwater exposure (commercial receptors on the site), surface soil exposure (commercial receptors, workers on site) and air exposure in open spaces (commercial receptors outside the site, at 25 m).
Exposure factors are volatilization, leakage/infiltration of polluting waters and wind erosion (Figure 7). Exposure routes for contaminated soil are dermal contact, ingestion,

inhalation; the ways of exposure to air are: volatilization and/or contaminated particles; the exposure routes for contaminated groundwater are: ingestion of groundwater or drinking water.

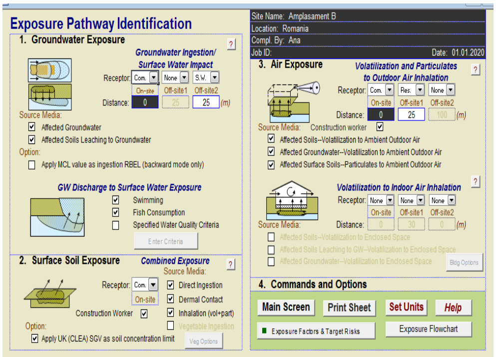


Figure 6. Exposure pathways - RBCA Toolkit software

The specific indicators of the soil pollutants on the site (risk factors) are: THP, benzene, ethylbenzene and xylene, and in the case of groundwater, the pollutants identified following the investigation are THP and benzene. In the risk assessment, the sample with the maximum concentration was considered without thickness of the free phase of the oil product identified during the measurements in monitoring periods.

Benzene is a complex compound of BTEX and difficult to degrade, with volatile properties and high solubility in water, so it presents a significant risk to human health (carcinogenic risk) and to the environment.

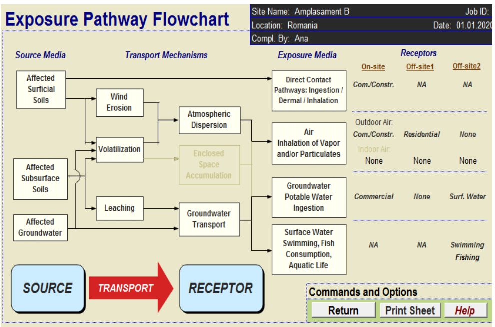
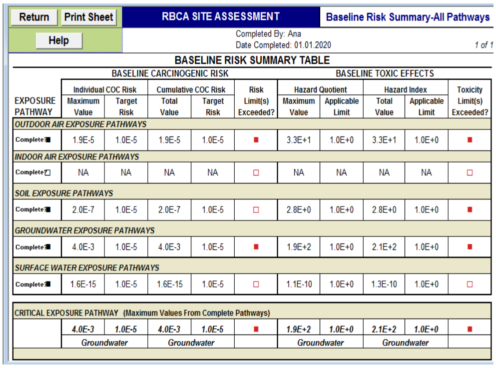


Figure 7. Exposure Pathway Flowchart - RBCA Toolkit software

The type of soil was chosen with specific parameters defined according to international literature, similar to the type of soil related to the specific site, and in the case of geological and hydrogeological data, the parameters was defined through in situ measurements.

The next figure (Figure 8) shows the results of the risk assessment for the warehouse.


Return | Print Sheet | RBCA SITE ASSESSMENT | Baseline Risk Summary-All Pathways
Help
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Date Completed: 01.01.2020
1 of 1

BASELINE RISK SUMMARY TABLE

EXPOSURE PATHWAY	BASELINE CARCINOGENIC RISK: Individual COC Risk – Maximum Value	Individual COC Risk – Target Risk	Cumulative COC Risk – Total Value	Cumulative COC Risk – Target Risk	Risk Limit(s) Exceeded?	BASELINE TOXIC EFFECTS: Hazard Quotient – Maximum Value	Hazard Quotient – Applicable Limit	Hazard Index – Total Value	Hazard Index – Applicable Limit	Toxicity Limit(s) Exceeded?
OUTDOOR AIR EXPOSURE PATHWAYS										
Complete? ■	1.9E-5	1.0E-5	1.9E-5	1.0E-5	■	3.3E+1	1.0E+0	3.3E+1	1.0E+0	■
INDOOR AIR EXPOSURE PATHWAYS										
Complete? □	NA	NA	NA	NA	□	NA	NA	NA	NA	□
SOIL EXPOSURE PATHWAYS										
Complete? ■	2.0E-7	1.0E-5	2.0E-7	1.0E-5	□	2.8E+0	1.0E+0	2.8E+0	1.0E+0	■
GROUNDWATER EXPOSURE PATHWAYS										
Complete? ■	4.0E-3	1.0E-5	4.0E-3	1.0E-5	■	1.9E+2	1.0E+0	2.1E+2	1.0E+0	■
SURFACE WATER EXPOSURE PATHWAYS										
Complete? ■	1.6E-15	1.0E-5	1.6E-15	1.0E-5	□	1.1E-10	1.0E+0	1.3E-10	1.0E+0	□
CRITICAL EXPOSURE PATHWAY (Maximum Values From Complete Pathways)										
	4.0E-3	*1.0E-5*	*4.0E-3*	*1.0E-5*	■	*1.9E+2*	*1.0E+0*	*2.1E+2*	*1.0E+0*	■
	Groundwater		*Groundwater*			*Groundwater*		*Groundwater*		

Figure 8. Carcinogenic and non-carcinogenic risk assessment using RBCA Toolkit software

The results are structured by risk categories, namely carcinogenic risk and non-carcinogenic risk, and by exposure routes. The output data highlight the following aspects:
- carcinogenic risk is identified for exposure by air (in open spaces, outdoor air) and for exposure through groundwater;
- the risk generated by toxicity (non-carcinogenic risk) is identified for the air exposure route (in open spaces, outdoor air), for the soil exposure route and for the groundwater exposure route.

As a result of the risk assessment, it is required that soil and groundwater to be decontaminated on the specific site to reduce the concentrations of pollutants to the acceptable levels for the human health and for environment.

CONCLUSIONS

The quantification of the risk is represented by the average daily dose that reaches the human body (receiver) through the pathways exposure (ingestion, dermal contact, inhalation, etc.) and by the daily tolerance coefficient, present at the level of the program in the database, established by the WHO (World Health Organization).

Considering the modelling results, a risk level above the admissible limits can be predicted for the receptors identified and presented at the level of the conceptual model site.

Carcinogenic and non-carcinogenic risk assessment is carried out by the two software, RBCA Toolkit and RISC 5, and the results of the risk assessment were different.

In the case of the site, the carcinogenic and non-carcinogenic risk is significant in several pathways' exposure calculated by the RBCA software compared to the carcinogenic and non-carcinogenic risk calculated by RISC 5 software.

In order to explain this situation, the similarities and differences between the two software are presented below, starting from the characteristic input data and output data.

From the point of view of the source of contamination and of the transport routes, the RBCA Toolkit software allows the assessment of the risk when we have contamination in the soil and in the groundwater and considering the migration and infiltration of pollutants from the unsaturated zone to the saturated zone. In the case of the RISC 5 software, the risk assessment is different, such that the risk is calculated separated for the unsaturated zone (soil) and the saturated zone (groundwater).

In terms of similarities, both software is using almost the same types of chemical substances / constituents of concern and allowed the introduction the same concentrations. Also, each software considers the homogeneous conditions in the field, and have a database of the properties of chemical substances, toxicity, geological, hydrogeological conditions, etc.

The differences between the software are also indicated at the level of the exposure pathways for the unsaturated zone and saturated zone. In the case of the RBCA Toolkit software, the important routes of exposure for soil (which could be selected as input data from the software) are: ingestion, inhalation of particles, volatilization and dermal contact; the routes of exposure for groundwater, if they are discharged into surface water: swimming and consumption of fish from contaminated water.

In the case of the RISC 5 software, the exposure routes for soil, specific for the site, are: ingestion, inhalation of particles, dermal contact, and in the case of groundwater, they are ingestion, dermal contact, and inhalation of particles.

The RBCA software allows entering the distance from the contaminated area to the receivers (2 receivers outside the site) but also mentions the receivers located at the site level, such as the workers during the remedial stage of the works.

The RISC 5 software allows entering the type of receivers without defining the distance to them; in this software, the sensitive receptors are also included separately, children for which the carcinogenic and non-carcinogenic risk calculation is performed separately. In the case of the RBCA Toolkit, the receivers are generically residential, including adults, children, adolescents, without making a difference between them, children for example.

Also, there are same differences between the software in the case of geological, hydrogeological and hydraulic parameters, for which in RBCA ToolKit parameters are defined for certain types of soil, while in the RISC 5 software, they are not defined.

To explain this situation, I present one such example, for which the RBCA software includes data on geological and hydrogeological parameters in the case of the dusty-sandy soil specific to the warehouse; in the case of the RISC 5 software this type of soil was not found and a sandy soil was considered. The RISC 5 software allows modifying the parameters already defined by the program depending on the need to reproduce the real situation in the field as faithfully as possible.

Another difference is the fact that each software presents risk assessment models and implicitly somewhat different calculation parameters considering the ways of exposure and transport of pollutants in the geological environment.

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