

Application of a risk management method to contaminated sites in Japan

Fujinaga, A.¹⁾, Uchiyama, I.²⁾, Morisawa, S.²⁾, Yoneda, M.²⁾,
Yoshioka, M.³⁾, Sasamoto, Y.⁴⁾

Abstract

In Japan, environmental criteria, which are set in case of drinking groundwater through lifetime, are used as criteria for contaminated soil and groundwater. On the other hand, USA and Netherlands manage contaminated sites by risk assessment (RA), which can consider site conditions. However, RA needs additional survey and analysis of the contaminated site.

A new framework was proposed for setting a practicable remediation goal of mixed contaminants in soil and groundwater to manage human risks due to exposure to the contaminants. The framework was applied as a case study on a contaminated site to determine the remediation goal, and it was discussed on its effectiveness and applicability. Exposure routes, for the site where groundwater is not used for drinking or for industrial use, are limited. Therefore, the soil/groundwater concentrations of remediation goal or risk-based concentration were set larger than environmental criteria without losing the estimated health risks. This may suggest that a wide variety of in-situ remediation methods such as monitored natural attenuation and bioremediation, which are difficult to achieve the Japanese environmental criteria in limited time, could be used for the practical candidate remediation methods.

Tasks to apply this risk management method in Japan are advertising health risk to the Japanese society, setting up Japanese RA method, evaluating toxicity for Japanese RA, and creating an official third party to approve RA. From now on, researchers, businessmen, and governors, who are related to RA, need to cooperate to solve these tasks. Then, residents can select RA as a useful method to manage contaminated sites.

*Keywords: Contaminated soil/groundwater, Human health risk,
Risk management method, Remediation goal*

- 1) Environmental Systems Engineering Course, Department of Industrial Systems Engineering, Osaka Prefectural College of Technology
- 2) Graduate of School of Engineering, Department of Urban and Environmental Engineering, Kyoto University
- 3) Hyogo Prefectural Institute of Public Health and Environmental Sciences.
- 4) Design and Technology Department. (Environmental Engineering), Civil Engineering Division, Konoike Construction Co. Ltd

1. Introduction

In order to judge existence of contamination in soil and groundwater, there are environmental criteria for soil and groundwater in Japan. The criteria are severe value, which are set for drinking. By using environmental criteria, it is easy to judge contamination. However, the method to use the criteria cannot consider the site condition. Therefore, countermeasures should do too much in order to achieve the criteria. It can waste asset for environmental conservation. On the other hand, environmental assessment used in USA can consider the site condition, but the work of environment risk assessment should be needed.

Then, by selecting site conditions from a flow diagram, risk based concentration (RBC) can be calculated. And the method is applied to the real contaminated site. This site was contaminated with tetrachloroethylene (PCE), trichloroethylene (TCE), and cis-1,2-dichloroethylene (DCE). In addition, RBC is calculated in consider with volatile organic carbon in air from non-point source (background). The management method is applied to a real contaminated site and the method is examined.

2. Risk Assessment

As a method of risk assessment, first of all, intake is calculated by concentration of contaminant at a contaminated site for each exposure route. And then, risk of human health can be calculated by using toxicity of the contaminant.

To calculate intake of contaminant, concentration of the contaminant in groundwater, in soil, and in surface such as river and lake are needed. Then, according to conditions of exposure at the site, intake for each route (groundwater, soil, surface water) is calculated.

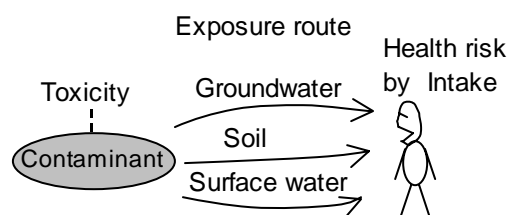


Figure 1. Image of risk assessment of contaminants on the site.

As an endpoint of health risk, noncancer risk is calculated by intake (I) divided Reference Dose (RfD) that is considered safety factor. If HI is less 1, it is considered that non-cancer diseases may not be occurred. And if there are several materials of same group such as PCE, TCE, and cDCE, sum of each HI is used for assessment.

3. Risk of ambient air

In order to evaluate health risk correctly, every exposure route

should be summed up. In this study, the main risk is from soil and groundwater. However, contaminant in ambient air and food might not be negligible¹⁾. Therefore, risk of PCE, TCE, and cDCE in ambient air is counted to the risk of soil and groundwater. As a background concentration, average concentrations (PCE 0.52 ug/m³, TCE 1.3 ug/m³, cDCE no data) of about 400 points all over Japan in 2001²⁾ are used for risk calculation. Total hazardous index (*HI*) is 0.074, which is much little than the acceptable value “1”. In addition, cancer risk becomes 1.1x10⁻⁶, which is much little than acceptable risk 10⁻⁵. Therefore, it can be said that the *HI* and the cancer risk of background do not effect much to total risk.

4. Setting method for risk-based concentration

4.1 Flow diagram of setting risk-based concentration (RBC)

Flow diagram of setting risk-based concentration at the contaminated site is shown in Figure 2. Risk-based concentration (RBC) should be calculated less than one of *HI* including background. If same chemical groups of contaminant exist, *HI* should be divided into each substance. Risk of same kind of contaminant would sum up³⁾, and then risk for each substance is divided by the number of the contaminants. For example, if three kinds of volatile organic chlorinated carbon exist in a contaminated site, a total acceptable risk of *HI* (=1) minus a risk of ambient air (*HI*=0.074), and divide the number of kinds. Then, *HI* of each substance is calculated (1-0.074)/3 = 0.31. The value is used for calculation of RBC. Cancer risk is also calculated according to the life excess risk level of 10⁻⁵. Smaller value is selected between calculated concentration from *HI* and *Risk*.

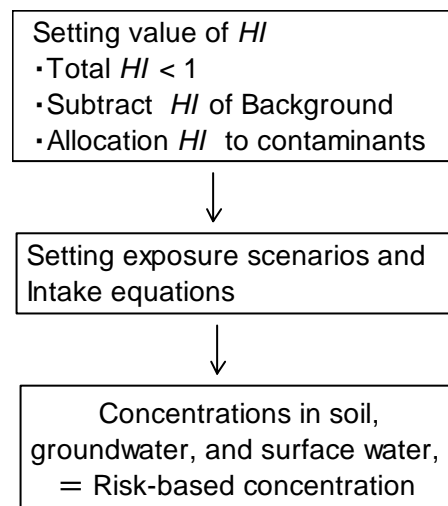


Figure 2. Flow diagram of risk-based concentration (RBC) for non-cancer contaminants

Next, exposure route is set according to site condition for each media (groundwater, soil, surface water) (Figure 3), and intake for each exposure scenario is calculated (4.2). Calculating equation for

intake has three variables (C_S , C_{GW} , C_{RW}), and also has many parameters.

4.2 Exposure Scenario

By the combination of exposure route, exposure scenarios are set (Table 1).

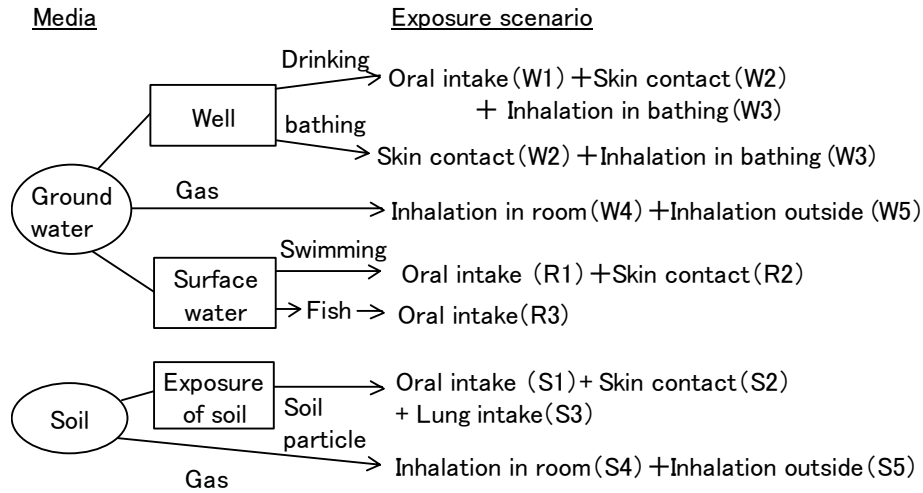


Figure 3. Exposure scenario in consideration of contaminated site

On the residential area, according to usage of groundwater, existence of surface water, and surface soil, twelve scenarios were set (No.1 to 12). Also, on the industrial area, according to existence of drinking groundwater, existence of surface soil, four scenarios (No.13 to 16) were set. Sixteen scenarios are totally set.

As intake, intake of groundwater (W1 to W5), intake of surface water (R1 to R5), and soil (S1 to S5) are calculated. Calculation of intake uses physical property of contaminant, parameters of soil, body, lifestyle, and others⁴⁾. Body weight^{5),6)}, lifetime⁷⁾, and intake of fish⁸⁾ are from Japanese data.

And then, each intake of exposure route is summed up. HI for each contaminant is shown in Equation 1. The equation has concentration of each media (soil, groundwater, and surface water) as variables, and it has also coefficients.

$$HI = k_{GW_i} \times C_{GW_i} + k_{S_i} \times C_{S_i} + k_{RW_i} \times C_{RW_i} \quad \text{Equation 1}$$

where

C_{GW_i} : concentration of contaminant “i” in groundwater (mg/L)

C_{S_i} : concentration contaminant “i” in soil (mg/kg)

C_{RW_i} : concentration contaminant “i” in surface water (mg/L)

k_{GW_i} : coefficient of C_{GW_i} (L/mg)

k_{S_i} : coefficient of C_{S_i} (kg/mg)

k_{RW_i} : coefficient of C_{RW_i} (L/mg)

4.3 Relation between groundwater, soil, and surface water

In order to calculate RBC of $HI=1$ and $Risk_T=10^{-5}$, the three kinds of variables should be one. Then, C_S is calculated in consideration of sorption/desorption to soil⁹⁾ by an equation that C_{GW} , Organic carbon-water distribution coefficient, fraction of organic carbon in soil (f) as shown in Equation 2.

$$C_S \text{ (mg/kg)} = Koc \times f \times C_{GW} \quad \text{Equation 2}$$

Where C_{GW} : Concentration of groundwater (mg/L)
 Koc : Carbon - water sorption coefficient (L/kg)
(PCE 155, TCE 166, cDCE 35.5 L/kg)¹⁰⁾
 f : fraction of organic carbon in soil (0.01)¹¹⁾

Table 1. Exposure scenario by combination of exposure route

Usage	Conditions			Exposure scenario No.
	Usage of well	Existence of surface water	Exposure of soil	
Residential area	Drinking : •W1+W2+W3 +W4+W5	Yes: +R1+R2+R3	Yes: +S1+S2 +S3+S4+S5	1
			No: +S4+S5	2
		No	Yes: +S1+S2 +S3+S4+S5	3
			No: +S4+S5	4
	Bathing : •W2+W3 +W4+W5	Yes : +R1+R2+R3	Yes: +S1+S2 +S3+S4+S5	5
			No: +S4+S5	6
		No	Yes: +S1+S2 +S3+S4+S5	7
			No: +S4+S5	8
	no use : •W4+W5	Yes: +R1+R2+R3	Yes: +S1+S2 +S3+S4+S5	9
			No: +S4+S5	10
		No	Yes: +S1+S2 +S3+S4+S5	11
			No: +S4+S5	12
Industrial area	Drinking : •W1+W4+W5	No	Yes: +S1+S2 +S3+S4+S5	13
			No: +S4+S5	14
	No use : •W4+W5		Yes: +S1+S2 +S3+S4+S5	15
			No: +S4+S5	16

And also, C_{RW} is set 10 times as C_{GW} , because wastewater quality standard in Japan is set 10 times as C_{RW} . The equation 1 is substituted to equation 3. The equation 3 gives C_{GW} and the value becomes RBCs. On the other hand, RBC of cancer risk can be got as same as non-cancer RBC.

$$0.31 = (k_{GWi} + k_{Si} \times Koc_i \times 0.01 + k_{RWi} \times 0.1) \times C_{GWi} \quad \text{Equation 3}$$

5. Result of RBC

By using methodology of RBC, the concentrations for a site contaminated with several contaminants. For example, RBC of cDCE in

groundwater of exposure scenario No.11 (no well, no surface water, existence of soil surface), three kinds of contaminants of PCE, TCE, and cDCE, is calculated as 3.9 mg/L. On the other hand, if contaminants are only cDCE, the concentration becomes 9.0 mg/L, which is three times as much as the concentration of three kinds.

Among exposure scenarios, minimum concentration is a scenario of drinking groundwater in residential area, the concentration of PCE, TCE, and cDCE is 0.0044 mg/L, 0.021 mg/L, 0.058 mg/L, respectively. Maximum concentration is for no-groundwater, no surface water, and no existence of soil surface, and the concentration of PCE, TCE, and cDCE are 4.6 mg/L, 1.9 mg/L, and 9.3 mg/L, respectively.

As a general, concentration for no drinking groundwater is 30 times to 460 times as much as drinking groundwater. And the concentration in industrial area is two times bigger than in residential area¹²⁾.

6. Application to contaminated site

The methodology of the setting RBC is applied to real contaminated site, and management method by using the concentration is evaluated.

6.1 Condition of contaminated site

In 1983, groundwater contaminated site with TCE was found on Hyogo prefecture in Japan. Contaminated source was a factory that used 12 ton of TCE per month from 1970¹³⁾. Pump-and-treat and excavation of the source was conducted on 1985, as a countermeasure of the contaminated source. Groundwater flows from the factory to south. The contamination is spread according to the groundwater flow (Figure 4).

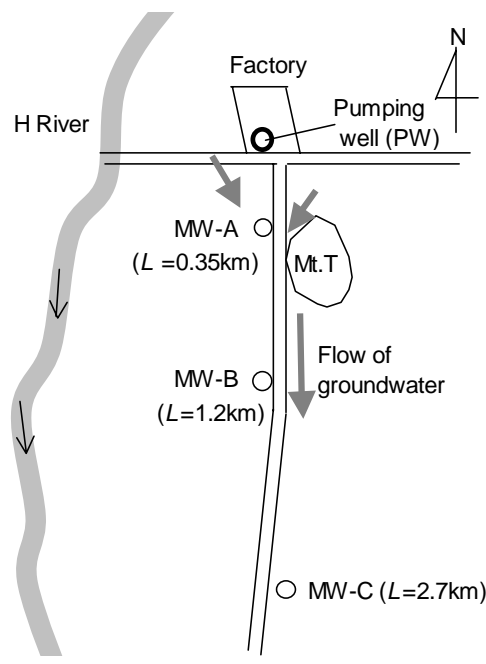


Figure 4. Image map of contaminated site model

Figure 4 shows variation of TCE concentration of groundwater(GW) from 1985 at monitoring well A (MW-A) (Distance from pumping well; L=0.35 km), monitoring well B (MW-B) (L=1.2 km), monitoring well C (MW-C) (L=2.7km) .

TCE concentration of each well decreases according to time. This means the countermeasure works effect. Seasonal variation is assumed that higher groundwater level in rain season elutes TCE into groundwater.

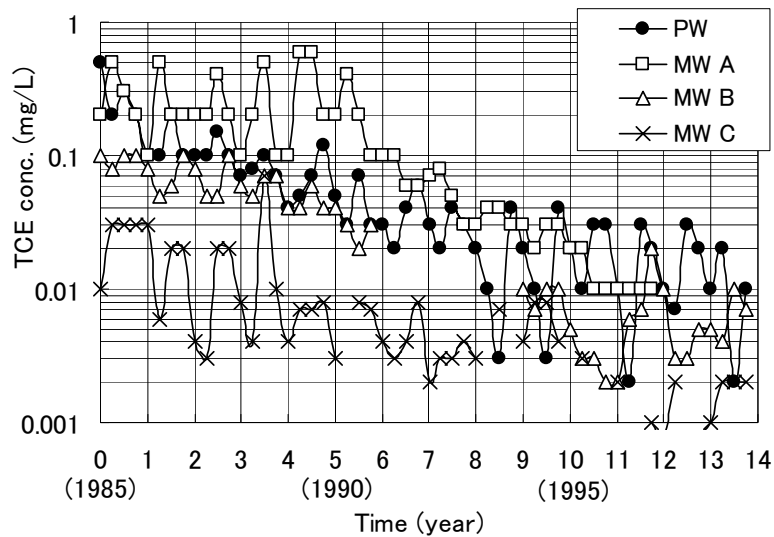


Figure 5. The variation of TCE concentration in GW at PW, MW-A, MW-B, MW-C.

6.2 Predicting future concentration by using mathematical model

In order to evaluate variation of concentration by Natural Attenuation, numerical analysis is conducted by using free code “Bioplume III”¹⁴⁾ of U.S.EPA, which considers two dimension transport and dispersion, and bioremediation.

According to Dr. Hirata’s report¹³⁾, velocity is set as 2×10^{-4} cm/sec, hydraulic gradient is set as 0.004 m/m, degree of porosity is set as 0.2.

First order reaction rate constant (k_b) is estimated by comparing the calculated concentrations with measured concentrations at pumping well. The k_b is selected from 2.5×10^{-4} to 2.5×10^{-3} (1/d).

The condition of simulation is as follows,

- Area: 3,300m(south to north) x 900m (east to west)
- Mesh interval: 150m x 150m
- Boundary condition: Water level of outside area is constant.
- Step number:100 (0.1 year for 10 years)

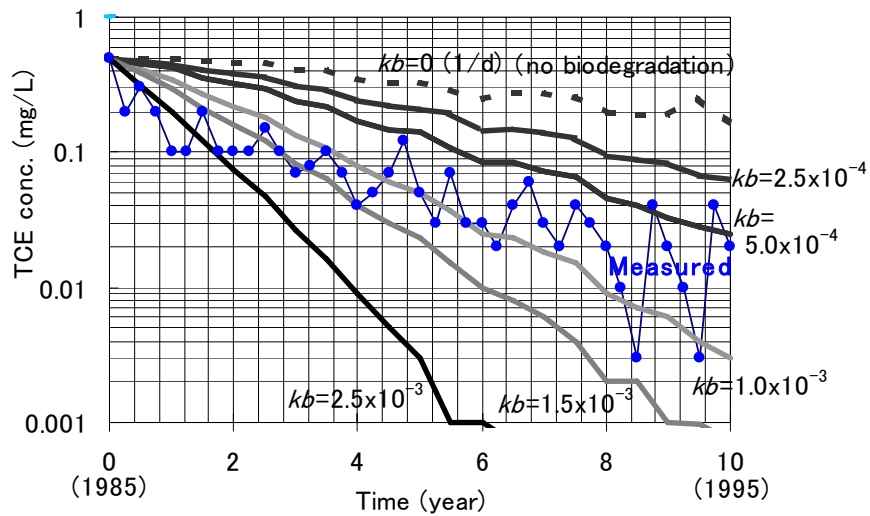


Figure 6. Calculated and measured TCE concentrations of groundwater

When k_b is 1.0×10^{-3} (1/d), calculated concentrations are nearest to measured concentrations until five years. After five years, measured concentration is not increased as calculation, and after ten years 5.0×10^{-4} (1/d) of k_b is well adapted. Therefore, the 5.0×10^{-4} (1/d) is selected. This value is between 1.4×10^{-4} and 2.5×10^{-3} (1/d)¹⁶, which are measured values in real sites. This result shows the condition in this site has no problem for bioremediation.

Also measured TCE concentrations and calculated values with 5.0×10^{-4} (1/d) of k_b at MW-A and MW-B are shown in Figure 7.

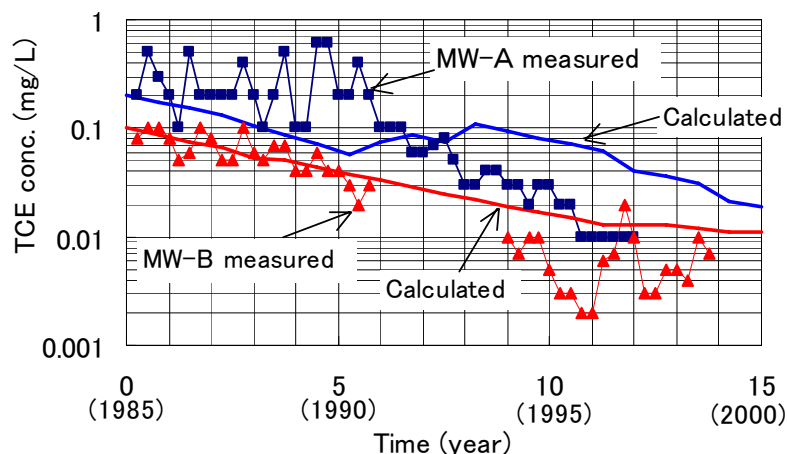


Figure 7. Measured and predicted TCE concentration of groundwater at MW-A and MW-B

Measured concentration at MW-A varies seasonally and is not decreased from 0.2 mg/L for 6 years. However, it is decreased after 6

years. On the other hand, calculated concentration is not decreased from 5 years to 10 years. This may be because influent of contaminant from upstream. Measured concentration at MW-B is decreased every year for 11 years from 0.1 mg/L to 0.002 mg/L. After 11 years, the concentration is increased up to 0.02 mg/L and then decreasing rate is decreased. On the other hand, calculated concentration is decreased also every year. This may be because contaminant is supplied by transport and dispersion from upstream.

6.3 Exposure scenario

Representative exposure scenario is selected from Table 1.

- Scenario 7: residential area, groundwater is used without drinking, soil surface is exposed
- Scenario 12: residential area, groundwater is not used, and soil surface is not exposed (is paved).
- Scenario 13: industrial area, groundwater is used for drinking, soil surface is exposed.
- Scenario of environmental criteria: in case that groundwater is used for drinking in residential area, RBC is almost same as environmental criteria. Therefore, environment criteria are used instead of RBC.

Especially, in this contaminated site, concentration of TCE, following an equation can be expressed. Therefore, the risk can be expressed only one variable of concentration of TCE (C_{TCE}).

6.3.1 Calculated RBC for the site

As a result, RBC of TCE and cDCE in the site is calculated in the site, are calculated by distribution of risk into TCE and cDCE (Table 2).

Table 2. RBC of GW, calculated by concentration ratio of TCE and cDCE at the site

No	Exposure scenario	RBC by HI		RBC by $Risk_T$
		TCE	cDCE	TCE
7	Residential, GW (no drinking), Soil exposure	1.7	0.99	1.3
12	Residential, no GW, no soil exposure	1.7	0.99	1.4
13	Industrial, GW (drinking), soil exposure	0.14	0.08	0.09
	Environmental Criteria	0.03	0.04	0.03

Bold letters are selected as RBC.

*) Acceptable $HI = 1 - 0.07 = 0.93$.

**) Acceptable $Risk_T = 10^{-5} - 1.1 \times 10^{-6} = 8.9 \times 10^{-6}$.

In Table 2, RBC in GW about scenario 7 and 12 are almost same.

The range of TCE concentrations is 1.3 to 1.4 mg/L, and cDCE concentration is 0.99 mg/L. About scenario 13, TCE is 0.09 mg/L and cDCE is 0.008 mg/L.

6.3.2 Application of risk-based concentration

After removal of contamination in 1985, most high concentration of TCE at PW is decreased to 0.5 mg/L. RBC is 1.3 mg/L or 1.4 mg/L, if there is no drinking water at residential area. Therefore, this area of TCE may not be influenced. This result shows that excavation and pump-and-treat work effectively.

6.3.3 Period to achieve RBC

The period of TCE concentration to RBC (0.09 mg/L) by Natural Attenuation is about 4 years at PW, almost 7 years at MW-A, almost 4 years at MW-B by real measured concentration. The result of decreasing TCE concentration by simulation of natural attenuation is about 6 years at PW, about 4 years at MW-A, about 1 year at MW-B.

As a result, if risk management do by using RBC for groundwater drinking at a factory. Therefore, natural attenuation, which is difficult to achieve environmental criteria for a short period, can be selected as remediation technology.

6.4 Discussion

In order to recover the environment of soil and groundwater all over Japan, the risk of human health rationally must be decreased. Excessive remediation is negative to promote recovery of contaminated site in Japan. For the purpose, scientists should show correct risk based on scientific data. Governments should provide enough information to residents, and also they should explain the proper level for remediation. Polluters should do proper remediation in order to prevent health damage of remediation.

In Japan, RBC on each contaminated site is not used for site management, and it may be difficult that Japanese accept the RBC instead of current environmental criteria.

However, if residents accept RBC, it is beneficial to Japan for promoting environment recovery. And then, this study would give useful information to residents and polluter in order to use RBC, which can prevent health risk economically or complete remediation based on environment criteria.

7. Conclusion

In this study, a methodology to set RBC for several contaminants on the site, and RBC is used on the real contaminated site. As a result, in situ remediation such bioremediation and NA, which is difficult to guarantee complete remediation in setting period, can be used by risk management using RBC on each site.

It can make it possible to decrease the health risk rationally. Therefore, in situ remediation can be applied more. Once RBC for each scenario is set according to this method, contaminated site can be managed by RBC in consideration of the condition of the site.

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