Foundation System for Contaminated Sites (Guideline)

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0. Abstract

The rapid development of urbanization has led to urban problems such as shortage of urban land, traffic jams, and environmental pollution, which seriously restricted the sustainable development of urbanization. The accumulation of heavy metals and organic matter in natural soil not only pollutes the soil and water environment, directly endangers people's physical and mental health, but also causes changes in the nature of foundation engineering, resulting in engineering damage and destruction. Therefore, it is necessary to deal with and control the problem of urban industrial pollution foundation, so that it cannot only meet the needs of environmental safety but also achieve the function of development and utilization.

The purpose of this guide is to provide appropriate remediation methods for contaminated sites. This guide provides a classification analysis for different pollutants, contaminated land (industrial sites, landfills). Conduct a study of the steps of the risk assessment procedure, including the definition of a conceptual model, the determination of contact point concentrations, actual risk calculation, decision evaluation, etc. And consider the foundation system issues, including the corrosion of the foundation by the polluted soil, the assessment of the foundation of the polluted soil, etc. During the whole process, monitoring is required, including personnel protection and vehicle control, process requirements for ex-situ disposal of contaminated soil and groundwater, treatment of the ‘three wastes’ in disposal materials, disposal of enriched media, and regular monitoring.

This guide provides cases classified by remediation technology for reference, including PRB technology case, chemical oxidation remediation case, chemical oxidation combined technology case, and ex situ thermal desorption technology case (This case mainly considers supervision).

1. Introduction

1.1 Research Background

With the rapid development of the urbanization process, the rapid development of the urbanization process has provided a strong and lasting impetus for the sustainable development of the economy, but it has also led to increasingly prominent urban problems such as urban land shortage, traffic congestion, and environmental pollution, which have seriously restricted the possibility of urbanization. continuous development.

During the construction and operation of industrial enterprises, the lack of strict pollution control and the lack or imperfection of environmental protection facilities lead to the intrusion of a large number of toxic and harmful heavy metals and organic pollutants into the soil and groundwater of the plant site area. Representative pollutants include lead, zinc, chromium, arsenic and other heavy metals, as well as organic pollutants such as petroleum hydrocarbons, organic pesticides, benzene series and polychlorinated biphenyls, making the original site a severely polluted industrial pollution site.

In the late 1980s, countries such as the United Kingdom and the United States began to study the problem of soil and groundwater pollution in soil caused by leakage of gas stations. About 8 million tons of petroleum substances enter the environment every year, most of which enter the soil. , resulting in oil pollution of soil. Statistics show that between 1989 and 1990, there were about 2 million underground gasoline storage tanks in the United States, of which 90,000 leaked. Statistics show that as of March 2004, there were about 680,000 underground oil storage tanks in use in the United States, of which 97% were used to store petroleum products, including some used oils. In addition, there were more than 1.5 million There are many abandoned or closed oil storage tanks. Almost all underground oil storage tanks of gas stations built before the 1970s have leaks, and most of the gas stations over 20 years old also have leaks. Gas stations have become the source of groundwater in the United States. largest source of pollution. British Shell Oil Company has also announced that 1 or 3 of the 1,100 petrol stations in the UK have polluted soil and groundwater. Over time, some gas stations that were built earlier have begun to leak due to the serious aging of underground oil storage tanks and oil pipelines. In addition, with the development of oil exploration and petrochemical industry in the oil field, leakage will inevitably occur during the extraction, transportation, processing and storage of oil and its related products, resulting in soil pollution.

Different from the surface pollution of agricultural arable land, the pollution depth of industrial polluted sites can reach tens of meters. The accumulation of heavy metals and organic matter in natural soil not only pollutes the soil and water environment, directly endangers people's physical and mental health, but also causes changes in the nature of foundation engineering, resulting in engineering damage and destruction.

Therefore, it is a major problem facing the sustainable development and construction of the city to deal with and control the problem of urban industrial pollution foundation, so that it cannot only meet the needs of environmental safety but also achieve the function of development and utilization.

1.2Research Purpose of Guideline

Due to the development of the national economy, the drainage of industrial and urban wastewater, the accumulation or filling of industrial waste and domestic waste, and the irrigation of sewage, etc., the country's soil pollution has become increasingly serious, and the environmental pollution problem has become increasingly prominent, which has become a constraint to the country's economic development bottleneck.

1.3Research Principles of Guideline

(1) To meet the current needs of environmental protection system establishment and environmental protection work

As a series of guiding documents for contaminated sites, this technical guide should be aimed at the national economy, human resources and social status, and it should meet the actual needs of the country's local treatment and restoration of contaminated sites and engineering technology. The formulation of technical guidelines can provide technical reference for technical practitioners, relevant government staff, and staff of relevant enterprises and institutions.

(2) Combination of science and practically

By investigating various remediation technologies, mastering their principles, characteristics and scope of application, and conducting technical and economic comparative analysis, screening the best remediation technologies for polluted soil and groundwater under different conditions, making the guide more scientific and instructive and operability.

(3) Representative and typical

The restoration technology and typical combination of restoration technologies with high practical value at home and abroad are selected, and a scientific restoration technology screening method is proposed according to the differences of pollutants, pollution media and pollutant types in different polluted sites, which can allow users to adapt to local conditions. Select the restoration technology and technology combination suitable for the site.

(4) Risk control on whole process

This technical guide reflects the idea of risk control in the whole process, from the reasonable selection of restoration technology to the prevention of secondary pollution in the restoration process. Require.

2. Contaminants

Different contaminated sites have different pollutants and corresponding remediation technologies. In chapter one, I will first introduce and classify different pollutants and introduce the general sources of pollutants

2.1Heavy Metal Pollutants

The heavy mental pollutants, usually, refer to metals whose specific gravity (density) is greater than 5 g/cm^3. The typical heavy metals include mercury, zinc, cadmium, lead, nickel and etc. Heavy metals or other compounds of heavy metals are high toxic, such as combined chromium and lead, elemental mercury and so on. The heavy metal pollution mainly comes from mining, metal smelting, paint manufacturing and so on. Representative pollutants include arsenic, lead, zinc, cadmium, chromium and etc.,

2.2 Organic Pollutant

Organic pollutants mainly come from chemical factories, gas stations, agriculture, etc. And the representative pollutants are benzene series, pesticides, polychlorinated biphenyls, etc. There are several different ways to classify organic pollutants.

The organic compounds are mainly divided into persistent organic compounds, organic halogenates, aromatic hydrocarbons, surfactants, petroleum hydrocarbon pollution, etc. However, the classification method has the repeatability. For example, polychlorinated biphenyls in persistent organic compounds also belong to organic halogenates. Aromatic hydrocarbons can be divided into monocyclic aromatic hydrocarbons. The polycyclic aromatic hydrocarbons contain only one benzene ring, such as benzene and benzene chlorine, nitro, methyl, ethyl and other substituted derivatives. Polycyclic aromatic hydrocarbons contain two or more benzene rings, such as biphenyl, naphthalene, anthracene, etc. Many aromatic hydrocarbons are volatile, known as volatile organic compounds (VOCs).

Persistent organic pollutants (pops) are semi-volatile and highly toxic pollutants that are difficult to degrade and highly fat soluble in the environment. These can be enriched and amplified in the food chain, and can migrate globally through various transport routes. The Stockholm Convention, which came into force in 2004, provides 12 POPs, including 9 pesticides (Aldrin, chlordane, DDT, dieldrin, isodieldrin, heptane, hexachlorobenzene, mirex, toxaphene), 1 industrial chemical (polychlorinated biphenyls), polychlorinated dibenzo-dioxins, and polychlorinated dibenzofuran; At its fourth session, held in Geneva, Switzerland, from 4-8 May 2009, the Conference of the Parties decided to include ten additional chemicals, including perfluoro octane sulfonic acid and its salts, perfluoro octane sulfonyl fluoride, commercial pentabromodiphenyl ethers, canopies, lindane, pentachloro benzene, α -6666, β -6666 and hexabromobiphenyl.

Organic halogenates include halogenated hydrocarbons, polychlorinated dioxins, organochlorine pesticides and so on. Polychlorinated biphenyls (PCBs) belong to halogenated hydrocarbon, which is a group of chlorinated aromatic compounds formed by replacing hydrogen atoms in biphenyls by multiple chlorine atoms. According to the different positions and numbers of hydrogen atoms replaced by chlorine in biphenyl molecules, theoretically, there should be 3 isomers in a chlorine compound, 12 isomers in dichloride, 21 isomers in trichloride, 210 isomers in PCBs, 102 of which have been identified so far.

Surfactant molecules have the material of hydrophobic and hydrophilic genes at the same time. And it can significantly change the liquid surface tension and interface tension, or the tension between the two phases. It has good emulsification and demulsification, wetting, penetration, or reverse wetting, dispersing, foaming, stability and the ability to increase the dissolved, according to its hydrophilic gene structure and types are classified.

Therefore, the classification of organic pollutants is as follows:

Number	**Classification**		**Typical pollutants**
1	**Volatile organic compounds （VOCs）**	Monocyclic aromatic hydrocarbons	Benzene, toluene, ethylbenzene, total xylene, chlorobenzene, nitrobenzene, styrene, etc.
		Non-aromatic compounds	Acetone, butanone, chloroform, carbon tetrachloride, dichloroethane, trichloroethane, vinyl chloride, etc.
2	**Semi-volatile organic compounds (SVOCs）**	Polycyclic aromatic hydrocarbons （PAHs）	Benzanthracene, benzopyrene, benzo fluoranthene, dibenzo anthracene, indenopyrene, naphthalene, phenanthrene, acenaphthene, anthracene, fluoranthene, fluorene, pyrene, etc.
		Non-aromatic compounds	2-chlorophenol, 2,4-dichlorophenol, 2-nitrophenol, pentachlorophenol, 2,4,5-trichlorophenol, 4-cresol, etc.
3	**Persistent organic pollutants(POPs）**	Pesticides	Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene
		Industrial chemical	PCBs
		By-products in production	Dioxins, Benzofurans
		New additional chemical material	Perfluoro octane sulfonic acid and its salts, perfluoro octane sulfonyl fluoride, commercial pentabromodiphenyl ether, commercial octabromodiphenyl ether,

			ketone, lindane, pentachlorobenzene, alpha-hexabromodiphenyl, beta-Hexahexahexanone and Hexabromobiphenyl
4	**Pesticide**		Dichlorvos, dimethoate, simazine, dimethoate, glyphosate, diazinon (Dianon), dysenzinc, etc.
	Total petroleum hydrocarbons（TPH）	Aliphatic hydrocarbons	Alkanes and alkenes above C7, cyclohexane, methylcyclohexane, benzene, toluene, benzopyrene, etc.
		Cycloalkanes	
		Aromatic hydrocarbons	
		Polycyclic aromatic hydrocarbons	
5	**Surface active agent**	Anionic surfactant	Carboxylates (such as soaps), sulfonates, sulfates, phosphates
		Anionic surfactant	Quaternary ammonium salts (such as disinfectants)
		Nonionic surfactant	Poly oxyethylene alkylamine

Table 1- classification of organic pollutants

Volatile organic compounds (VOCs) are ubiquitous pollutants in oil-contaminated sites, and these exist in the form of non-aqueous fluids in groundwater environment. They can be divided into two types according to density: those whose density is less than water is called light non-aqueous fluids, and those whose density is greater than water is called heavy non-aqueous fluids. In the polluted area, VOCs usually exist in the form of liquid phase, gas phase and NAPLs phase. They have obvious fluid properties, so they often exist and migrate in the form of multiphase flow, and are affected by a series of physical, chemical and biological processes. After surface leakage, NAPLs migrates downward into the unsaturated soil layer, and then migrates into the aquifer environment with rainfall and surface runoff. In the area it flows through, some pollutants remain in the porous media due to adsorption, dissolution and capillary interception. In addition, due to volatilization and dissolution, the pollutants in the stratum will form a gaseous distribution area in the unsaturated area, and a pollutant plume will form in the saturated area. With the change of groundwater, the pollutants can migrate horizontally and vertically, causing harm to the groundwater environment and human health.

3. Contaminated Land (industrial sites, landfills)

3.1 Basic concepts of contaminated sites

A contaminated site refers to a site that carries hazardous substances due to accumulation, storage, treatment, disposal or other means (such as migration), and is confirmed to be more hazardous than the acceptable risk level of human health or ecological environment after investigation and risk assessment, also known as a contaminated site. A site is defined as the sum total of soil, groundwater, surface water and all structures, facilities and living things within a site; A contaminated site is defined as a site where, after investigation and risk assessment, it is confirmed that the pollution hazard exceeds the acceptable risk level for human health and ecological environment. Polluted soil is generally defined as the soil that has undergone chemical changes due to the invasion of external filth. Polluted foundation refers to the foundation with physical, chemical and mechanical changes of natural soil invaded by external pollution-causing substances.

3.2 Impact of polluted sites on structures

3.2.1 Introduction

The above analysis shows that the basic physical and mechanical properties of soil will be changed obviously and the engineering properties of soil will be changed. For the existing building foundation, when the foundation is polluted during its use, it will lead to different forms of foundation damage.

3.2.2 Types of Corrosion Damage Modes

It can be seen from the case studies that there are two main corrosion damage modes of buildings on contaminated sites:

(1) acid, alkali, organic and other pollutants infiltrate into the building foundation, change the physical and mechanical properties of the foundation soil, resulting in uneven settlement or uplift of the foundation, leading to the destruction of the superstructure;

(2) acid, sulfate, chloride and other pollutants in liquid or gaseous form directly cause corrosion on the superstructure, resulting in concrete cracking, crushing, strength reduction, steel corrosion. To sum up, it is necessary to carry out site pollution risk assessment and carry out necessary repair and treatment on the contaminated site to make it meet both environmental pollution control requirements and engineering design and use requirements.

3.3 Industrial Polluted Sites

3.3.1 Classification of Industrial Polluted Sites

（1） Inorganic pollution

Inorganic pollution is an important type of pollution in industrial pollution structure. It is very common. It mainly refers to the infiltration of soil environment into inorganic pollution, so that the original soil geological environment is broken, and some toxic and harmful substances are constantly released, which poses a great threat to the health of residents. For example, heavy metals such as Co, Pb, Cu and Cd are common inorganic pollutants. Manufacturing industries such as leather manufacturing, chemical enterprises and smelting industry are the main enterprises causing heavy metal pollution.

（2） Organic pollution

Pollution is also a kind of important organic matter pollution type, the organic pollution is the main reason of the result into the organic matter in soil environment, and the original ion complexing reaction, formation of complex compound, on soil structure, physical and chemical properties caused great influence, such as pesticides, pah, benzene products is the main source of organic matter pollution, some significant toxic organic pollutants itself, such as benzene ring products, with the passage of time, there will be a lot of secondary toxic and harmful substances released to the outside, causing a great impact on the safety of the environment. Such as paint and coatings, pesticide production, electronic products and many other industries are the main cause of organic pollution.

（3） Compound pollution

In addition to the above pollution types, in the process of comprehensive pollution control, complex pollution control is very difficult. The so-called compound pollution mainly refers to that there are two or more types of pollutants in the site, and the content and distribution of pollutants are poor. In terms of treatment, it is necessary to fully combine with regional modules to divide different application structures, so as to effectively treat industrial contaminated sites. At present, in many industrial polluted sites, the pollution types are complex, and most of the pollutants often have synergistic and antagonistic effects, which make the soil pollution structure more complicated. In the finishing process, it is very difficult, and the processing work is also very complicated.

3.3.2 Contents of the investigation of industrial polluted sites

（1） First phase

To carry out the corresponding investigation on the industrial contaminated site environment, the work of the first stage is to effectively collect the preliminary data, which is an important content of the basic work. The task is to fully understand and master the situation of industrial contaminated sites and pollution types, and make accurate judgment on the status quo of pollution in the site. The first stage work is not to collect samples of contaminated sites, just according to the relevant information, the feasibility about judgment, if contaminated sites in new construction conforms to requirements before the corresponding research work, in the actual investigation, is mainly used to collect related basic data, or into the scene to carry out the stepping out and the corresponding research by visiting.

（2） **Second phase**

After determining whether the industrial contaminated site has utilization value, it is necessary to carry out the second stage of contaminated site investigation. At this time, structural sampling is needed to fully clarify the actual types and content of pollutants on the site, obtain corresponding data, and better guide the later treatment work. In practical application, this stage mainly includes preliminary sampling and detailed sampling.

（3） **Third phase**

After the completion of the data survey in the second stage, it is necessary to carry out the third stage. In this stage, the main work is to make up the basic situation of the test. In the process of sample collection in the second stage, some errors caused by human factors and environmental factors will lead to the failure of test results. This needs in the third phase offset work, better ensure the precision of the data analysis result, and give full consideration to the second stage survey data, according to the actual situation of the industrial pollution shall be detailed risk assessment, in accordance with the need to site to carry out the detailed measurements, obtain comprehensive and accurate data, ensure the precision of testing results.

3.4Landfill contaminated sites

3.4.1 Introduction to Garbage Disposal Methods

The widely used processing methods:

（1） Sanitary landfill method
（2） Incineration method
（3） Composting method
（4） Heat treatment
（5） Ocean abandonment method

In developed countries, landfill is the main way of urban garbage disposal. Sanitary landfill has become the main means of municipal solid waste in many countries because of its large capacity, strong adaptability, one-time treatment, no residue, convenient management and reasonable operation cost. This approach also has disadvantages. The requirements for site selection are often high, and it is generally difficult to find a site that meets all the requirements. At the same time, there are also many environmental problems. Secondary pollutants such as landfill gas and leachate generated in the landfill process, if not properly disposed, will cause serious pollution to the surrounding water, air and soil, and pose a threat to the public health of nearby areas.

3.4.2 Pollution of soil by garbage

Soil pollution caused by garbage is usually produced by landfill and dispersion of garbage. The soil pollution caused by garbage disposal is mainly caused by the infiltration of garbage leachate into the soil layer.

（1） Definition and composition of landfill leachate

Landfill leachate refers to the sewage generated by the rainwater that exceeds the saturated storage capacity and surface evaporation potential of the soil layer covered by garbage after entering the landfill site and passing through the soil layer covered by garbage. Leachate also includes water contained in garbage itself, water generated by garbage decomposition and groundwater immersion.

In summary,

i. Leachate is the main component of landfill pollution to the surrounding geological environment. The disadvantage is that the rainfall and the design defects of the landfill provide a channel for the leachate to pollute the geological conditions.
ii. Leachate is an important factor of groundwater and surface water pollution, which can conceal the groundwater pollution around it and is closely related to the geological conditions of the site.
iii. Leachate is the carrier of heavy metal pollution, which can promote the absorption of heavy metals by soil and the migration of leachate in heavy metals.
iv. The pollution of landfill site to surrounding environment should be mainly prevented,

supplemented by treatment and monitored in real time. Once the surrounding environment is polluted, reasonable methods and technologies should be adopted to repair it according to the specific pollution situation.

（2） **Basic characteristics of landfill leachate**

The contents of COD, BOD5, ammonia nitrogen and heavy metals in landfill leachate are high. In the landfill without seepage prevention measures, a large amount of landfill leachate will directly penetrate into the surrounding soil under the effect of atmospheric rainfall leaching and scouring, and the harmful components in the leachate will destroy the normal living environment of soil microorganisms and have harmful effects on soil structure and soil quality. Moreover, a large number of heavy metals in the leachate will be enriched in the soil layer, resulting in serious soil heavy metal pollution.

（3） **Influence of landfill leachate on basic physical and chemical properties of soil**

Under the influence of leachate, the nutrient content of soil around the landfill area increased significantly. The contents of organic matter and total nitrogen in soil increased greatly. The contents of organic matter and total nitrogen in the soil at different distances from the heap were significantly higher than those in the control area, especially in the soil at the nearest 1m away from the heap.

The order of heavy metal pollution to soil by landfill leachate is CD > Cu > Zn > Mn > Pb.

The results showed that heavy metals in landfill leachate accumulated in soil, which resulted in heavy metal pollution in soil around the landfill area.

3.4.3 Countermeasures for Landfill Leachate Prevention and Control

As for the pollution of garbage disposal site to the environment, the protection should be given priority and the site selection of garbage disposal site should be done well. There are two different methods to solve the environmental pollution problem of garbage disposal site. One is natural dilution theory, that is, choose to pile garbage on good underground aquifer, and its pollutants will be lost through the dilution of aquifer. The other is to find a good waterproof layer site or the bottom of low-lying areas of clay tamping, after the water can be stacked garbage, garbage leachate and gas through chemical treatment after recycling, accepted for most landfill sites. The causes and mechanism of air, surface, groundwater and soil texture environmental pollution in comprehensive landfill site are analyzed, and the following corresponding prevention and control measures should be taken:

（1） MSW was preprocessed.

（2） The site selection of landfill should be far away from the water source and the soil layer with poor permeability as far as possible, and there is no big fracture and fault. The lower soil layer of landfill should be thickened and encrypted, and the waterproof material should be laid appropriately.

（3） We should avoid and reduce the infiltration of external water, so that the formation of leachate as little as possible, such as the design of the top cover layer, and set up a strong seepage prevention system at the bottom of the landfill, to avoid the leakage of leachate.

（4） The collection, discharge and purification of landfill leachate are designed to stabilize the groundwater level at a certain depth.

（5） Groundwater quality monitoring is carried out in the landfill to grasp the dynamic influence of leachate on groundwater and improve the environmental protection measures in time.

（6） For the polluted waste site, the further spread of pollution should be controlled as far as possible, so that the pollution of the waste site is limited within a certain range.

（7） It is the basis of pollution control and treatment to establish the simulation forecast of geological environment pollution in landfill site.

（8） For pollutant treatment, extraction treatment, in situ physical and chemical treatment and microbial treatment can be adopted.

4. Risk assessment procedures

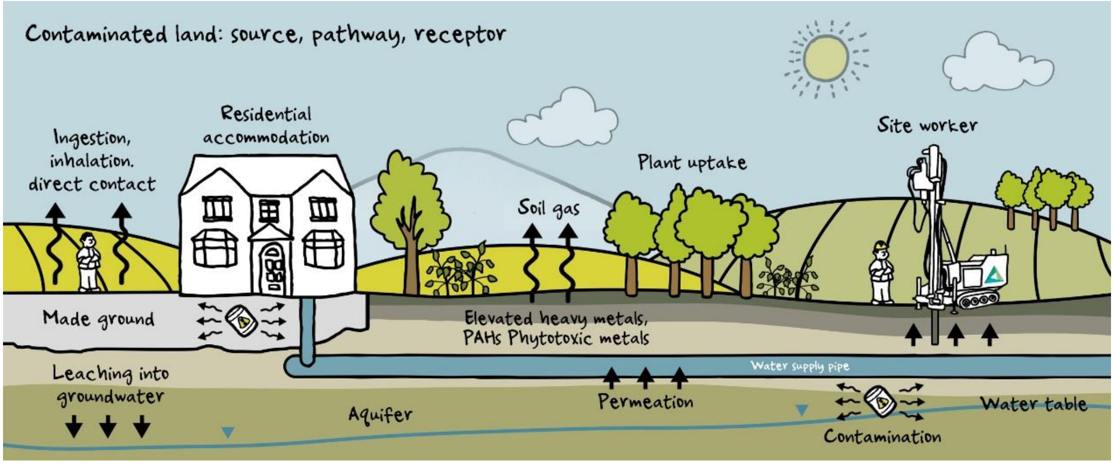
Importance and necessity of developing technical guidelines for human health soil environmental benchmarks. Protecting human health is one of the core contents of soil environmental standards. Human health soil environmental reference value is the minimum value of carcinogenic and non-carcinogenic end points in human health risk assessment, and the reference value obtained is a purely scientific value. For the same protected object, different countries may have different soil environmental reference values due to different general site parameters, pollutant exposure pathway and migration model, and health exposure risk of critical population. However, both European and American countries have established soil environmental standards for human health. Based on the acceptable risk level, for example, non-carcinogenic hazard level, the acceptable risk Quotient (HQ) is less than or equal to 1, for carcinogenic hazard level, the hazard is less than 10-6 or 10-5 or 10-4, and combined with the exposure assessment model and risk assessment model, the critical content of the contaminant in the soil is back-derived.

The main principle of human health risk assessment is the concept of environmental health risk assessment put forward by American Academy of Sciences, including risk identification, toxicity analysis, exposure assessment and risk assessment. The default exposure pathways, exposure assessment and pollutant migration models, and human exposure parameters are not identical in different exposure scenarios, leading to differences in the specific implementation of the framework to formulate soil environmental benchmarks in different countries. The technical methods specified in this code mainly refer to the environmental health risk assessment concept of the American Academy of Sciences and the technical methods of human health risk assessment of the United States Environmental Protection Agency. The main reason is that the United States is one of the countries that carried out soil environmental benchmark research earlier, and its relevant legal standards and technical standards are relatively perfect, and the study of calculation model and parameters is relatively systematic, with a large degree of information openness, which is convenient for inquiry and reference.

There are 3 essential elements:

- Source (A source of contamination (in soils, groundwater or surface water);
- Pathway (A pathway or route by which a receptor can be exposed to, or affected by, a contaminant);
- Receptor (A receptor that could be adversely affected by a contaminant).

The combination of these three elements (source-pathway-receptor) describes a ‘pollutant linkage’; without any one of these elements, there is no pollutant linkage and no resulting risk, ie the presence of a contaminant is not, in itself, sufficient to pose a potential risk. And the pollutant linkage can be presented by a picture.



Picture 1-Pollutant Linkage

The RA approach is structured in a logical sequence of phases progressing from site assessment investigations to risk management decision making. In particular, the following steps can be identified.

- Site investigation;
- Definition of the conceptual model;
- Determination of concentrations at the point of exposure;
- Risk calculation;
- Decision assessment.

4.1Site investigation

Site assessment includes all the environmental investigations required to characterize the source of contamination and the environmental components affected by the pollution. The aim of Environmental investigation are mapping the source of contamination and the chemo-physical characterization of the affected environmental components.

4.1.1 **Introduction**

The investigation of contaminated sites is the basis for site environmental management, site utilization planning and development and construction. In addition to the routine engineering investigation, it is necessary to find out the composition, distribution range and pollution degree of pollutants, and evaluate their impact on human health and engineering properties. At home and abroad, corresponding indoor and on-site in-situ test evaluation methods have been developed.

4.1.2 **Survey and Investigation of Polluted Sites**

Contaminated site survey and investigation is the front end of the contaminated site management process, in risk assessment, pollution control repair and planning of the field before use, its purpose is to try to accurately describe in detail the site hydrology engineering geological conditions, characteristics and distribution of groundwater and soil pollution, provide site characteristic parameters, provide data support for the site risk assessment. It provides the basis for making the site management and restoration plan economically and effectively and making the land use plan rationally.

（1） Survey and investigation stages and procedures

The thesis divides the site environmental investigation into three stages, as shown in the figure:

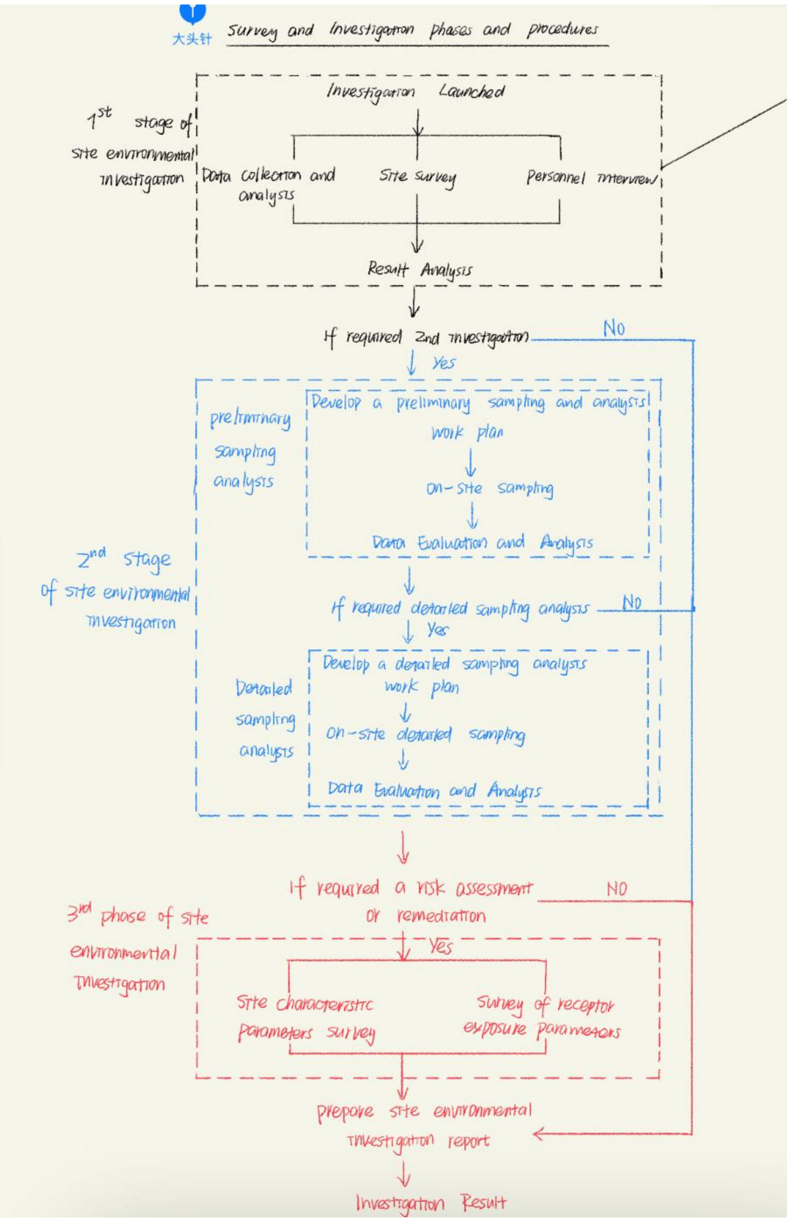


Figure 1- site environmental investigation

（2） Content of survey and investigation

i. <u>Phase 1 Site Environmental Investigation</u>

In the stage of pollution identification, data collection, site visits and personnel visits are mainly adopted, and on-site sampling analysis is not carried out in principle. Data collection mainly includes: site utilization change data, site environmental data, site related records, relevant government documents, as well as natural and social information of the region where the site is located; When there is a possibility of mutual contamination between the investigation site and the adjacent site, the relevant records and data of the adjacent site shall be investigated. The main contents of site reconnaissance include: the current situation and historical situation of the site, the current situation and historical situation of the adjacent site, the current situation and historical situation of the surrounding area, regional geology, hydrogeology and topographic description, etc. The site survey shall mainly be conducted within the site and include the surrounding areas where pollutants may migrate. The focal points of site survey should include: the use, treatment, storage and disposal of toxic and harmful substances; Production process and equipment status; Foul, chemical and pungent odors, traces of contamination and corrosion; Drainage pipes or channels, sumps or other surface bodies of water, waste dumps, Wells, etc. Through site survey, we can preliminarily judge the pollution situation of the site. Personnel interview mainly interviews the insiders of the current situation or history of the site, including the personnel of the site management department, the user department and the third-party personnel familiar with the site, etc., focusing on the questions involved in data collection and site survey, information supplement and textual research of existing materials. The phase I investigation should identify possible sources of contamination in and around the site and conduct an uncertainty analysis. If there are possible sources of contamination, the possible types of contamination, status and source of contamination shall be described and recommendations for a phase II site environmental investigation shall be made.

ii. <u>The second stage of site environmental investigation</u>

The second stage of site environmental investigation is the pollution confirmation stage based on sampling and analysis. If the first stage of site environmental investigation indicates that there is a possible pollution source in or around the site, the second stage of site environmental investigation will be carried out as a potential polluted site to determine the type, concentration (degree) and spatial distribution of pollutants. The method of sampling analysis is mainly adopted, which can be divided into preliminary sampling analysis and detailed sampling analysis. On the basis of the first phase investigation, a work plan for preliminary sampling and analysis is designated, which includes tasks such as verification of available information, determination of possible distribution of contaminants, development of sampling programmers, designation of health and safety protection plans, development of sample analysis programmers and determination of quality assurance and quality control procedures. Sampling programmers generally include: Sampling site layout, sample quantity, sample collection method, on-site rapid testing method, sample cell phone, storage, transportation and storage requirements.

For the horizontal layout of sampling points, please refer to the following table:

Point layout method	**Conditions of Use**
System random distribution method	It is suitable for sites with uniform pollution distribution.
Professional judgment method	It is suitable for sites with well-defined potential contamination.
Zoning method	It is suitable for sites with uneven distribution and obtaining pollution distribution.
System layout	It is applicable to all kinds of site conditions, especially when the pollution distribution is unclear or the pollution distribution range is large.

Table 2- horizontal layout of sampling points

The soil sampling depth in the vertical direction of the sampling point can be determined and set according to the location, migration, formation structure and hydrogeological conditions of the pollution source. If the site information is not well understood and it is difficult to reasonably judge the sampling depth, the sampling position can be set according to the equal spacing of 0.5-2m.

For groundwater, clean comparison points should be selected near the investigation site under normal circumstances. The layout of groundwater sampling sites should consider hydrogeological conditions such as groundwater flow direction, permeability of hydraulic slope aquifer, buried depth and thickness, and migration and transformation of pollution sources and pollutants. Existing groundwater monitoring Wells within the site or adjacent areas can be used as groundwater sampling points or comparison points.

Sample detection items should be determined according to the conservative principle, according to the potential pollution sources and pollutants inside and outside the site determined by the first-stage investigation, while considering the migration and transformation of pollutants, sample monitoring and analysis items; For uncertain items, potential typical contamination samples can be selected for screening and analysis. General industrial sites can choose to detect items: heavy metals, volatile organic compounds, semi-volatile organic compounds, cyanide and asbestos, etc. If soil and groundwater are obviously abnormal and conventional detection items cannot be identified, biological toxicity test can be used to screen and judge.

According to the initial sample analysis result, if the concentration of pollutants are more than national and local standards and clean the concentration of control point, and through the uncertainty analysis confirmed that don't need to be further investigation, the second phase space environment investigation can end, or think there may be an environment risk, should be a detailed sample analysis, determine the pollution degree and range.

According to the results of preliminary sampling analysis, combined with site zoning, customized sampling scheme. The system point method should be used to encrypt the sampling method. The sampling unit area should not be larger than 1600m2(40m×40m grid) for the area where the boundary range of pollution needs to be delimited. The vertical sampling depth and interval are determined according to the preliminary sampling results.

The second stage site environmental investigation report should put forward the main contents of the site pollutant composition and distribution characteristics.

iii. Phase III Site Environmental Investigation

On the basis of the second stage survey, a third stage site environmental survey should be carried out if risk assessment or pollution remediation is required. The third stage of site environmental investigation mainly includes supplementary sampling, field test and laboratory test. The main work content includes the investigation of site characteristic parameters and receptor exposure parameters to obtain parameters needed for risk assessment and soil and groundwater remediation.

The characteristic parameters of the investigation site include: analysis data of physical and chemical properties of soil samples from different representative locations and soil layers or selected soil layers, such as soil, PH, bulk density, organic carbon content, water content and texture, etc. Information and data on climatic, hydrological and geological characteristics of the site (site), such as annual mean surface wind speed and underwater transmission system. According to risk assessment and actual needs of site restoration, appropriate parameters were selected for investigation. Receptor exposure parameters include: land use pattern, population and buildings in the site and surrounding area. The third stage site environmental investigation report shall meet the needs of site risk assessment and pollution remediation.

4.1.3 Methods for investigation of contaminated sites

The sampling, field testing and site characteristic parameter determination in the second and third stages of the above site environmental investigation need to be completed by using special geotechnical engineering investigation methods. The investigation methods mainly include drilling sampling, on-site contamination testing, groundwater observation well layout and test, geophysical methods, etc.

（1） Drilling sampling

The investigation of polluted site is to add the investigation of pollutant characteristics on the basis of engineering geology and hydrogeology investigation. Exploration methods include drilling, well exploration, trough exploration, geophysical exploration, etc. The selection of drilling method and technology comprehensively considers the characteristics of pollutants in the formation structure of contaminated site, rock-soil characteristics, environmental sensitivity, etc., and meets the requirements of formation discrimination, sampling and in-situ test. The optimal drilling method is selected from common drilling methods. Pollution loss, cross contamination and secondary pollution should be prevented during exploration.

Well and trough exploration can be used for field pipeline pollution investigation and shallow vadze pollution sampling, etc. The demarcation limit of exploration depth is generally 3m.

The layout of exploration sites should be determined according to the principles of environmental investigation, and the distribution of pollution sources and pollutant migration characteristics should be considered in the detailed investigation stage.

In the investigation of contaminated sites, soil samples can be collected by direct penetration sampling. Quality control and quality assurance plan should be made before sampling implementation. Surface soil samples are generally collected by digging, generally using simple tools such as shovels, shovels and bamboo slices. Deep soil samples are mainly collected by drilling holes. The collection of soil samples for routine testing of geotechnical parameters should conform to the relevant codes of geotechnical engineering. For volatile organic samples, the disturbance to the sample should be reduced as far as possible. Firstly, the on-site portable identification device should be used for scanning, and at the same time, samples should be taken and quickly transferred to the brown sample bottle with sealing agent; For other types of pollutants, samples should be collected with clean sampling tools and transferred to brown glass bottles for compaction and sealing. For heavy metal contaminated samples, portable heavy metal analyzer should be used for advanced on-site scanning, and then samples should be sent to the laboratory for analysis.

Groundwater samples should be collected in groundwater monitoring Wells and should be carried out within 2 hours after the completion of monitoring Wells to ensure that all contaminants or rock damage caused by drilling and fine particles from natural rock formations must be removed. Portable equipment can be used to measure groundwater temperature, PH, conductivity, turbidity and REDOX potential before collection. The construction process of groundwater monitoring well is divided into design, drilling, selection and installation of filter tube and well tube, selection and loading of filter material, as well as sealing and fixing.

Samples should be properly stored and transferred after collection. After soil samples are collected, appropriate containers should be selected for storage according to the physical and chemical properties of pollutants. Voc contaminated soil samples and odorous contaminated soil samples should be packaged in sealed sampling bottles, which should fill the entire container space; Suitable sealing measures can be taken for samples containing easily decomposed organic matter to be determined. Samples should be transported and stored in a low temperature environment below 4°C to avoid volatilization loss during transportation and storage. They should be analyzed and tested as soon as possible after being sent to the laboratory.

（2） On-site contact sampling method

i. Geoprobe system

Geoprobe is specially designed and developed for soil and groundwater pollution investigation projects. Geoprobe system is a platform that integrates multiple functions. According to the system functions, it can be divided into soil and groundwater sampling system, monitoring well completion system, contaminated site remediation injection system, MIP test system for on-site detection of VOC pollutants, conventional CPT system, etc. This guide describes the 6620DT device, which has the advantages of small size, convenient operation, and high efficiency。

Soil and groundwater sampling systems can be divided into DT32, DT21, MC5, RS60, LB, etc. DT21 soil sampling system is widely used. Its unique direct pressing device can take out the original soil samples, and its unique soil casing can protect the quality of samples well. The groundwater sampling system (SP16) can reach a predetermined depth very quickly and take out groundwater samples at a specific depth.

Monitoring well formation system: Geoprobe equipment is superior in setting up long-term monitoring Wells by drilling a hollow spiral drill pipe to a specific depth. The inner cavity of the spiral drill pipe is isolated from the underground soil, and the filter layer with a predetermined thickness is maintained when the flower-tube is inserted. In addition, the upper layer is filled with bentonite to form a long-term monitoring well.

Contaminated site remediation injection system: mainly used in contaminated site remediation, GS2200 injection machine can provide enough mud pressure, can be injected into the contaminated underground soil, especially suitable for in-situ soil remediation projects.

MIP system: It is a detector that can detect soil and groundwater pollutants and the detector can be placed on the surface. The computer screen tool can tell the depth of the contaminant, but cannot determine what compound the contaminant is. Therefore, MIP has two advantages: it can detect contaminants in the field and is suitable for a variety of soil textures.

Underwater Profile Rod Tool System (HPT): This system, manufactured by Geoprobe, is used to assess the water pressure characteristics of subsurface soils. As the tool drills into the ground at a fixed rate, pressurized water is injected into the soil through a screen on the probe rod. An on-line pressure sensor measures the reactive pressure of soil injected with pressurized water. This reaction pressure is related to the ability of the soil to conduct water. Pressure and water flow are recorded as well as depth.

ii. <u>Soil and water sampling system based on CPTU</u>

Static probe technology (CPT) has developed to the direction of pore pressure static probe technology (CPTU) and multi-function in recent years. The above Geoprobe system is combined on the basis of CPT system to achieve multi-function for other functions and meet the needs of contaminated site investigation. In recent years, a device based on CPT to collect soil, water and gas samples has been developed. The device uses CPT penetration system to connect soil samples.

Most CPT penetration sampler designs are based on the original Gouda or MOSTAP soil sampler in the Netherlands. The pickers are closed until they are pushed to the depth required. The Gouda sampler has an internal cone tip that is retracted back into the locked position, leaving a hollow sampler with a small diameter (25mm/1 inch) stainless steel or brass tube that is then inserted into the soil to collect samples.

（3） Groundwater monitoring well

Groundwater monitoring well is one of the important parts of the field investigation of contaminated sites. The monitoring well is mainly used to measure the groundwater level, find out the distribution conditions of groundwater and take underground salicylate. Monitoring test Wells are also used to provide hydrogeological parameters for hydrogeological tests.

The location of monitoring Wells is determined according to the distribution of pollution sources and the diffusion of pollutants. In the section, the distribution pattern of well should be determined according to the distribution of water-bearing layer, water-repellent layer and confined aquifer. According to the well structure, the groundwater environmental monitoring Wells used in polluted sites can be divided into single-pipe single-layer monitoring Wells, single-pipe multi-layer monitoring Wells, nest monitoring Wells and cluster monitoring Wells.

The structure of groundwater monitoring well is mainly composed of well hole, well tube, filler and well platform. Pipe diameter and wall thickness are important parameters for monitoring Wells. Representative demand for water sampling and well safety should be considered. If the inner diameter of the well pipe is too large, the groundwater velocity is too large. When it exceeds a certain value, turbulence will occur, which will lead to the fine particles in the soil layer entering the well and affect the detection effect. If the pipe diameter is too small, sampling is difficult and efficiency is low. The thickness of shaft wall is mainly controlled by strength. This guide recommends the selection of DN50mm (2 in.) PVC well pipe, consistent with the ASTM standard in the United States; When the monitoring well is used as a pumping test or repair well, the well pipe is DN100mm, and the diameter of the drilled hole should be at least 100mm larger than the diameter of the well pipe, that is, to ensure that the thickness of the packing layer is greater than 50mm.

The material selection of monitoring well pipe mainly considers the compatibility of material and groundwater. When the monitoring target pollutant is organic matter, stainless steel material should be selected. When the monitoring target pollutant is inorganic or groundwater is highly corrosive, PVC material should be selected. The compatibility assessment of monitoring well material and groundwater quality is shown in the following table.

Filling design is also one of the important parts of the monitoring well, the main filter layer, secondary filter layer, sealing layer, backfill layer, etc., the material of each packing layer should meet the requirements of the specification. The filter layer is mainly made of quartz sand with different particle sizes, the sealing layer is mainly made of bentonite particles, and the backfill layer is made of cement slurry or cement slurry bentonite mixture.

Typical reactive substances in groundwater	**Monitoring well material**						
	PVC	Galvanized steel	Carbon steel	Low carbon steel	304 stainless steel	316 stainless steel	Teflon
Micro acid	100	56	51	59	97	100	100
Weak acid	98	59	43	47	96	100	100
High TDS	100	48	57	60	80	82	100
Organic matter	64	69	73	73	98	100	100

Table 3- Monitoring the compatibility of well pipe material with groundwater

Note: The higher the score is, the more applicable it is. For example, 100 means very applicable, while less than 50 means not applicable.

4.2Definition of a conceptual model

The conceptual model includes:

- the identification of exposed scenarios;
- the identification of exposed receptors;
- the identification of exposure pathways;
- the identification of migration pathways;
- the selection of the constituents of concern (COCs).

The content of exposure assessment includes determining the exposure scenarios and main exposure pathways of people to pollutants of concern in contaminated sites under specific land use patterns, pollutant migration models and exposure assessment models, model parameter values, and calculating the exposure amount of exposed people

4.2.1 The definition of exposure scenarios and land use method

Under different land use methods, the sensitive population and main exposure routes of pollutants are different, because the evaluation models and model parameters involved are also different. In the process of backward deduction of soil environmental reference value, the carcinogenic risk of pollutants is equal to the maximum acceptable risk level divided by the product of carcinogenic exposure per unit weight of average life cycle and carcinogenic slope factor. The soil environmental base value of the non-carcinogenic risk of the pollutant is equal to the product of the reference dose exposed to the soil and the maximum acceptable hazard quotient divided by the non-carcinogenic risk exposure per unit body weight of the average life cycle. Reference dose of slope factor and cancer is concerned with nature of pollutants itself, for the average life cycle per unit volume of cancer or not carcinogenic exposure quantity calculation mainly depends on the mode of land use, exposure pathways, exposure model and model parameters are selected, so you must land in the standard way, way of exposure, exposure model and uniform exposure parameters.

(1) Determination of exposure scenarios and division of sensitive groups in the standard

Exposure scenario refers to the situation that site pollutants reach the recipient population through different exposure paths under specific land use.According to the activity patterns of people under different land use patterns, this Standard defines exposure scenarios under two typical land use patterns, namely, exposure scenarios of sensitive land represented by residential land (referred to as "sensitive land") and non-sensitive land represented by industrial land (referred to as "non-sensitive land").

- Sensitive land: residential land for urban construction, land for cultural facilities, land for primary and secondary schools, and land for orphanages for social welfare facilities;
- Non-sensitive land: including industrial land, logistics and storage land, commercial and service facilities land and public facilities land in urban construction land

In addition to these two types of classification, it is necessary to analyze the possibility, frequency and period of exposure of people in specific sites, and make assessment by referring to sensitive or non-sensitive sites or construct exposure scenarios suitable for specific sites for risk assessment.

(1) Under sensitive land use, both children and adults may be exposed to site pollution for a long time, resulting in health

hazards. For carcinogenic effect, the lifetime exposure hazard of the population is considered, and the lifetime carcinogenic risk of pollutants is generally assessed according to childhood and adult exposure. For non-carcinogenic effects, children with lower body weight and higher exposure are generally evaluated according to childhood exposure.

(2) In the case of non-sensitive land use, the adult exposure period is long and the exposure frequency is high, so the carcinogenic risk and non-carcinogenic effect of pollutants are generally evaluated according to the adult exposure.

Different land use patterns, including agricultural land, residential/public land, commercial service land and industrial land, were considered in the development of human health soil environmental benchmarks, and the default exposure scenarios for each pattern were defined.

Main exposure approaches and evaluation models of residential land, non-residential land and construction land.

- **Residential land**: in the form of residential land, children are sensitive to the non-carcinogenic effect of pollutants, while adults are sensitive to the carcinogenic effect of pollutants.
- **Non-residential land**: non-residential land includes commercial and industrial land where indoor or outdoor workers are vulnerable to carcinogenic or non-carcinogenic effects of pollutants. Commercial space includes a church, a nursing home, a garage and a large storage area. Industrial land includes the location of public facilities, transportation service area and manufacturing in a broader sense.
- **Construction land**: under construction land, construction personnel are sensitive to carcinogenic or non-carcinogenic effects of pollutants

According to the activity patterns of people under different land use modes, this code selects residential and public land, commercial service and industrial exposure scenarios. The descriptions of land use modes and sensitive groups corresponding to the two exposure scenarios are shown in the figure below.

	Exposure scenarios	**Land descriptions**	**Sensitive crowd**
1	Residential and public land	(1) Ordinary house, apartment, villa, etc； (2) Kindergarten, schools； (3) Hospital；	Children (non-carcinogenic effect) Adults

		(4) Amusement park, park, etc。	(carcinogenic effect)
2	Commercial and industrial land	(1) Shopping malls, supermarkets and other types of retail land and its affiliated land; (2) Hotels, hotels and other accommodation and catering land; (3) Office space, financial activities and other commercial and financial land; (4) Car washes, gas stations, exhibition venues and other commercial services land; (5) Industrial production sites, land for ancillary facilities of industrial production, material storage sites, material transit sites, etc.	Adults (carcinogenic and no-carcinogenic effects)

Table 4-Activity patterns of people under different land use patterns

The main exposure pathways to be considered in land use are shown in the table below.

Exposed way		**Residential land**		**Industrial/Commercial Land**				**Building construction site**			
		topsoil	sub soil	Outdoor worker		Indoor worker		Construction workers		Off-site residents	
				top soil	sub soil	top soil	sub soil	topsoil	sub soil	topsoil	subsoil
Direct exposure route	Oral intake	√	√	√	√	√		√	√		
	Skin contact	√	√	√	√			√	√		
	Inhalation of soil particles	√		√				√		√	
Indirect exposure route	Inhale indoor air		√				√				
	Inhale outdoor air		√		√				√		
Groundwater pathway	Drinking groundwater contaminated		√		√		√				

	with soil leaching solution		
Crop route	Eat home-grown vegetables	√	√

Table 5- Main exposure pathways

4.2.2 Determination of exposure receptors

It considers mainly,

（1） Exposure to oral soil ingestion, skin contact with soil, inhalation of soil particles, inhalation of pollutant vapors from soil and groundwater in outdoor air, and exposure to pollutant vapors from soil and groundwater in indoor air;

（2） Non-volatile pollutants do not consider the vapor route of inhaled pollutants in the air;

（3） Air vapour routes of pollutants from soil into indoor air are not considered in planned land uses where there are no buildings (e.g. playgrounds, parks and green Spaces).

4.2.3 Identification of migration pathways

Migration refers to the change of the spatial location and range of pollutants in the environment, which is often accompanied by the change of pollutant concentration in the environment. The modes of migration are as follows: physical migration, chemical migration, biological migration and mechanical migration. The migration of pollutants is affected by their physical and chemical properties and environmental conditions, and the rate, scope and dominant form of migration will change.

(1) Mechanical migration

According to the mechanical migration of pollutants in the environment, they can be divided into three kinds of mechanical migration: gas, water and gravity.

i. Mechanical migration of gas

It Includes the free diffusion of pollutants in the atmosphere and the role of air transport.

The influencing factors include meteorological conditions, topography, emission concentration and emission height.

General rule: pollutant emissions in the atmosphere is proportional to the average wind speed and vertical mixing height is inversely proportional.

ii. Mechanical migration of water

It includes the free diffusion of pollutants in water and transport by water flow

General rule: the concentration of pollutants in water is directly proportional to the discharge of pollution sources, and inversely proportional to the average flow rate and the distance from pollution sources.

iii. Mechanical migration of gravity

It mainly includes the sedimentation of suspended pollutants and artificial transport.

(2) Physical migration

The mechanical movement of pollutants in the environment, such as the movement and diffusion of water and air flow, and the settlement under the action of gravity

(3) Chemical migration

They generally involve physical migration, while biological migration involves chemical and physical migration. It also refers to the migration of pollutants through chemical processes, including dissolution, dissociation, REDOX, hydrolysis, complexation, chelation, chemical precipitation, biodegradation, etc.

(4) Biological migration

Pollutants are transported by biological processes such as absorption, metabolism, reproduction and death of organisms.

Some pollutants (as some of the heavy metals and organochlorine stable organic compounds) once absorbed by organisms, it is difficult to rule out creatures in vitro, these substances will be accumulated in organisms, and through the further enrichment and food chain makes the physical environment of the pollutant content in organism to hundreds of times, thousands or even millions of times.

4.2.4 Determination of exposure pathways

For sensitive and non-sensitive sites, it specifies 9 main exposure pathways and exposure assessment models, including oral intake of soil, skin contact, inhalation of soil particles, the inhalation of outdoor air gaseous pollutants from surface soil, inhaled outdoor Air China from gaseous pollutants in the subsoil, suction gas from the lower soil pollutants in indoor air, a total of 6 kinds of soil pollutants exposure pathways and outdoor air inhaled from the groundwater of gaseous pollutants, inhalation of indoor air. There are three exposure channels of groundwater pollutants in gas: gaseous pollutants from groundwater and groundwater.

And determination of division of sensitive groups in the standard. There are four types of land use: agricultural land, residential land/public land, commercial land and industrial land. Under the four types of land use, the main exposure pathways to be considered are shown in the table below.

However, there are 5 main exposure routes that need to be considered under the land use method stipulated by the US EPA. See the table below.

Exposure scenarios		**Agricultural land**	**Residential/ Public Land**	**Commercial use land**	**Industrial land**
Direct exposure route	Oral ingestion of soil	√	√	√	√
	Skin contacts with soil	√	√	√	√
	Absorb soil particles	√	√	√	√
Indirect exposure route	Inhalation of gaseous pollutants from surface and subsoil in outdoor air	√	√	√	√
	Inhalation of gaseous pollutants from subsoil in indoor air		√	√	√

Table 6-5 Main exposure routes under the land use method stipulated by the US EPA

It should be noted that even in the same type of land use, exposure routes may vary depending on the specific exposure of receptors and pollutants. The determination of exposure pathways in specific scenarios should follow the following principles:

i. Under the same exposure scenario, a larger exposure scenario may contain more exposure pathways than a smaller exposure scenario.
ii. Direct exposure to any pollutant is considered.
iii. Indirect exposure to volatile pollutants is also considered, especially gaseous pollutants from the underlying soil in the inhaled indoor air.
iv. In open-air situations (such as parks, etc.), there is no need to consider the exposure route of "inhaling gaseous pollutants from the underlying soil in indoor air".

The detailed introduce of five human health risk assessment exposure models:

(1) Direct route of exposure - oral ingestion of soil

In the case of residential land use, different formulas were used to calculate the carcinogenic soil environment -- 97 -- reference value and non-carcinogenic soil environment reference value respectively when evaluating the carcinogenic and non-carcinogenic soil environment risk through oral intake of soil.

In general, the risk of cancer is assessed with adults as the sensitive population, and the main parameters include:

1) Soil pollutant concentration;
2) According to the age-adjusted soil intake factor, the daily soil intake of children and adults, the exposure period of children and adults, and the average body weight of children and adults can be calculated;
3) Exposure frequency;
4) Oral absorption efficiency factor;
5) Carcinogenic slope coefficient of oral ingestion and absorption;
6) Acceptable risk of cancer;
7) Mean duration of carcinogenic effect.

In the case of residential land use, the non-carcinogenic soil environmental baseline values are evaluated with children as the sensitive population; in the case of industrial/commercial land use and building construction land use, adults are evaluated as the sensitive population. The main parameter values include:

1) Soil pollutant concentration;
2) Daily soil intake;
3) Exposure frequency;
4) Exposure period;
5) Average body weight;
6) Oral intake and absorption efficiency factor;

7) Oral intake of reference dose;
8) Distribution coefficient of reference dose exposed to soil;
9) Acceptable hazard quotient;
10) Average time of harmful effects of pollutants.

(2) Direct exposure route - skin contact with soil

The reference value of carcinogenic soil under residential land use was calculated by taking adults as the sensitive population. Non-carcinogenic soil environmental baseline values were evaluated with children as the sensitive population. For commercial and industrial (non-residential) and construction land, both carcinogenic and non-carcinogenic risks were assessed by indoor or outdoor adults as sensitive population.

Carcinogenic risk in adults by skin-to-soil approach was calculated based on the following parameters:

1) Pollutant concentration in soil;
2) Skin contact factor adjusted for age. The exposed skin area, skin surface soil adhesion coefficient, exposure period and average body weight of sensitive population were calculated.
3) Absorption efficiency factor of skin contact with human body;
4) Skin contact absorption carcinogenic slope factor;
5) Frequency of skin contact events;
6) Exposure period;
7) Exposure frequency;
8) Average weight;
9) Mean time of carcinogenic effect;
10) Acceptable risk level.

The main extrapolated parameters of the non-carcinogenic soil environmental baseline values for children's skin-to-soil approach include:

1) Soil pollutant concentration;
2) Exposed skin surface area on children's body surface;
3) Children's skin surface soil adhesion coefficient;
4) Absorption efficiency factor of skin contact with human body;
5) Reference dose absorbed by skin contact;
6) Frequency of skin contact events;
7) Exposure period;
8) Exposure frequency;
9) Average body weight;
10) Mean time of non-carcinogenic effect;
11) Acceptable hazard merchant.

The calculation methods and main parameters of carcinogenic and non-carcinogenic risk (hazard factor) of oral ingestion of soil by adults were similar to those of residential land for commercial and industrial (non-residential) and construction land. However, the values of model parameters are different because the activity patterns of sensitive groups are different under different land use methods.

(3) Direct exposure route - inhalation of soil particulate matter

Using adults as sensitive population to evaluate the carcinogenic risk of soil pollutants in residential land use. The main parameters derived from the reference values of soil environment include:

1) Soil pollutant concentration;
2) Soil particulate emission factor, which is a parameter related to ground cover condition, annual average wind speed and other specific site meteorological conditions. The US Environmental Protection Agency calculates soil particulate emission factor values in different regions based on regional climate conditions.
3) Exposure period;
4) Exposure frequency;
5) Respiratory and inhalation carcinogenic slope factor;
6) Average weight;
7) Acceptable risk of cancer;
8) Mean time of carcinogenic effect.

In the case of residential land use, the non-carcinogenic soil environmental reference value was calculated with children as the sensitive population. The non-carcinogenic soil environmental reference values of children inhaling soil particulate matter through respiration were mainly calculated according to the following parameters

1) Soil pollutant concentration;
2) Soil particulate matter release factor;
3) Respiratory inhalation reference dose;
4) Exposure frequency;
5) Exposure period;
6) Average weight;
7) Non-carcinogenic hazards can be accepted;
8) Average time of non-carcinogenic effects.

For commercial and industrial (non-residential) land use and construction land use, both carcinogenic and non-carcinogenic risk soil environmental baseline values were calculated with indoor or outdoor adults as sensitive population. The calculation method and main parameters are similar to those of residential land, but the values of some parameters are slightly different. In the form of construction land,

the exposure risk of soil particles to the surrounding population after migrating to the surrounding area was also considered.

(4) Indirect exposure route - inhalation of gaseous pollutants from surface and subsurface soil in outdoor air

The main model parameters for calculating soil environmental reference values of gaseous pollutants inhaled from soil in outdoor air include:

1) Soil pollutant concentration;
2) Soil to outdoor air volatile factors;
3) Exposure period;
4) Exposure frequency;
5) Respiratory and inhalation carcinogenic slope factor;
6) Reference dose for respiratory inhalation;
7) Average weight;
8) Acceptable risk of cancer;
9) Acceptable hazard merchant;
10) Mean time of carcinogenic effect;
11) Mean time of non-carcinogenic effects.

The soil-to-outdoor vapor volatilization factor is a key parameter for assessing the risk of exposure to gaseous pollutants from soil in inhaled outdoor air. According to the characters of meteorological parameters, the pollutants in the physical and chemical properties, diffusion coefficient, diffusion coefficient, water pollutants in the atmosphere distribution coefficient in different environmental media) and the parameters of the soil physical and chemical properties (density, total pore volume, pore water volume ratio, pore air volume, etc.), such as parameter estimation of soil to the outdoor air volatilization factor.

The ASTM system takes into account the exposure contribution of volatilization of contaminants from soil at different depths into the air when assessing the risk of exposure to gaseous contaminants from soil in the inhalation of outdoor air. The exposure risk assessment models of pollutants volatilized into outdoor air in surface soil (less than 1m) and subsoil (less than 1m) were established respectively. The main evaluation model parameters include:

1) Physical and chemical properties of soil and capillary layer

including bulk density, total pore volume ratio, pore air volume ratio, soil organic carbon content, etc.

2) Physical and chemical properties of pollutants including diffusion coefficient in air, distribution coefficient in medium, dimensionless Henry's constant, etc.;
3) Soil and climate characteristic parameters including the length of the contaminated area parallel to the dominant wind direction, the annual average surface wind speed, the thickness or depth of the soil layer, etc.
4) Other population exposure parameters and pollutant toxicity properties parameters.

(5) Indirect exposure route - inhalation of gaseous pollutants from the underlying soil in indoor air

When evaluating the exposure of gaseous pollutants from soil in inhaled indoor air, Johnson and Ettinger (J&E model,1991) model is mainly used as the basis to consider the exposure of soil pollutants volatilizing into buildings. In this exposure process, the concentration of gaseous pollutants from soil in indoor air is estimated by the product of the concentration of soil pollutants and the concentration attenuation coefficient after volatilization of soil pollutants into indoor air. The concentration attenuation coefficient after volatilization of soil pollutants into indoor air is mainly calculated by the following parameters:

1) Physical and chemical properties of soil and capillary layer (including bulk density, total pore volume ratio, pore air volume ratio, soil organic carbon content, pollutant vapor permeability, etc.);
2) Physical and chemical properties of pollutants (including diffusion coefficient in air, distribution coefficient in medium, dimensionless Henry constant, etc.);
3) Soil and climate characteristic parameters (including soil pollution concentration, soil layer thickness or buried depth, soil surface and indoor air pressure difference);
4) Building characteristic parameters (including indoor and outdoor air exchange rate, floor tile thickness, crack depth under the foundation, length, width and height of the room).

Vapor invasion is the process by which polluted gas migrates from soil or groundwater to indoor space. It is important to note that the EPA has proposed a new vapor invasion model for assessing indoor vapor invasion exposure to petroleum hydrocarbon pollutants in terms of exposure pathways from soil gaseous pollutants inhaled into indoor air.

4.2.5 Determination of model parameters

The main model parameters in the risk assessment process can be divided into five categories:

1) Exposure parameters;
2) Soil property parameters;
3) Physicochemical properties and toxicity parameters of pollutants.

(1) Exposure parameters

Exposure parameters are important factors to evaluate the dose of human body exposed to external substances and have obvious regional and ethnic characteristics. The study of exposure parameters is the main work in improving health risk assessment in the world.

i. Average adult weight (BW_a, kg)

ii. Average weight of children (BW_c, kg)

iii. Average adult height (H_a, cm)

iv. Average children height (H_c, cm)

v. Adult exposure duration (ED_a, a)

The adult exposure period was determined by referring to the federal parameter value of the United States, and the recommended value of adult exposure period for agricultural land use was 24. The recommended exposure period for adult residents is 30 for residential/public land and agricultural land, and 25 for commercial and industrial land.

vi. Children exposure duration (ED_c, a)

For residential/public land and agricultural land, the recommended exposure period for children is 6.The recommended value is based on the parameters in the United States and the Netherlands.

vii. Adult exposure frequency (EF_a, d/a)

The recommended value for residential/public land and agricultural land is 350 according to THE REGULATIONS of USEPA (2002); The recommended value for commercial and industrial use is 250.In the case of commercial and industrial land use, adults work 5d per week and 52 weeks per year, excluding 11d of annual legal holidays, EF_a= 5D/week ×52 weeks/A-11D /a=250d/a.

viii. Children exposure frequency (EF_c, d/a)

The recommended exposure frequency for children in residential/public land and agricultural land is 350.

ix. Frequency of adult indoor exposure (EFI_a, d/a)

Based on the analysis of population activity characteristics, it is assumed that adults spend 75% of their time in indoor activities, and the recommended value is 350×0.75=262.5d/a for residential/public land and agricultural land, and 250×0.75=187.5d/a for commercial and industrial land.

x. Frequency of children indoor exposure (EFI_c, d/a)

The indoor exposure frequency of children under residential/public land and agricultural land is the same as that of adults, and the recommended value is 262.5; Children's access to commercial and industrial land is controlled and restricted, with a recommended value of 0.

xi. Outdoor exposure frequency for adults (EFO_a, d/a)

The recommended value is 87.5d/a (350×0.25) for residential/public land and agricultural land, and 62.5d/a (250×0.25) for commercial/industrial land, assuming that 25% of adult time is spent outdoors.

xii. Outdoor exposure frequency for children (EFO_c, d/a)

The indoor exposure frequency of children under residential/public land and agricultural land is the same as that of adults, and the recommended value is 87.5; The recommended value for commercial and industrial land use is 62.5.

xiii. Mean time of non-carcinogenic effect (AT_{nc}, d)

According to the relevant regulations of THE United States (USEPA,1996), 2190d is calculated for residential/public land and agricultural land; For commercial and industrial use, it is calculated as 9125d for adult.

xiv. Mean duration of carcinogenic effect (AT_{ca}, d)

xv. Daily soil intake for adults/children ($OSIR_{a/c}$, mg/d)

According to the relevant regulations of THE US Environmental Protection Agency (USEPA,1996), the recommended daily amount of soil intake for adults in all land use forms is 100; The recommended daily amount of soil for children is 200.

xvi. Soil adhesion coefficient of adult/child skin surface ($SSAR_{a/c}$, mg/cm^2)

According to the relevant regulations of THE United States Environmental Protection Agency (USEPA,1996), the recommended values of soil adhesion density on the skin surface of adults and children under residential/public land and agricultural land are 0.07 and 0.2, respectively. The recommended value of soil adhesion density for adult skin surface under commercial and industrial land use is 0.2.

xvii. Adult/child skin exposure ratio ($SER_{a/c}$)

Use exposure ratios in the RISK Assessment Guidelines for US Superfunds (USEPA,2004) as recommended values. For residential/public land and agricultural land, the recommended skin exposure ratio for adults is 0.32 and that for children is 0.36. The recommended adult skin exposure ratio for commercial/industrial use is 0.18.

xviii. Adult/child exposed skin surface area ($SAE_{a/c}$, cm^2)

Adult/child exposed skin area was calculated using the skin exposed area formula of the United States (USEPA,1990).

$$SAE = 239 \times H^{0.417} \times BW^{0.517} \times SER \; cm^2$$

Adults:

$$SAE_a = 239 \times 161.5^{0.417} \times 56.8^{0.517} \times 0.32 = 5145 \; cm^2$$

(Residential/Public land and Agricultural Land Methods)

$$SAE_a = 239 \times 161.5^{0.417} \times 56.8^{0.517} \times 0.18 = 2894 \; cm^2$$

(Commercial service land and industrial land)

Children:

$$SAE_c = 239 \times 113.1.5^{0.417} \times 19.2^{0.517} \times 0.36 = 2670 \; cm^2$$

(Residential/Public land and Agricultural Land Methods)

xix. Frequency of daily skin contact events (E_v, a time/d)

Referring to the relevant regulations of the United States (USEPA,2002), the recommended frequency of skin contact event is 1 time per day.

xx. Daily air intake of adults/children ($DAIR_{a/c}$, m^3/d)

According to the US Environmental Protection Agency (USEPA,1996), children's daily air respiration is 50% of adults' daily air respiration, so the recommended daily air respiration for children is set at 7.5.

xxi. PM_{10} particle content in the air (PM_{10}, mg/m^3)

Particulate matter PM10 refers to particulate matter with aerodynamic equivalent diameter ≤10μm in ambient air, also known as inhalable particulate matter.

xxii. $PM_{2.5}$ particle content in the air (PM_{10}, mg/m^3)

$PM_{2.5}$ refers to particulate matter with aerodynamic equivalent diameter ≤2.5μm in ambient air, which can also be called fine particulate matter.

xxiii. Proportion of particulate matter from soil in indoor/outdoor air (f_{spi}, f_{spo}, dimensionless)

Referring to f_{spi} regulations in the Netherlands, the recommended ratio of particulate matter from soil in indoor air is 0.8. The proportion of particulate matter from soil in outdoor air is 0.5.

xxiv. Oral absorption efficiency factor (ABS_o)

Refer to Europe and the United States (USEPA, 1996;RIVM, 1994), and the recommended parameter value is 1.

xxv. Skin contact absorption efficiency factor (ABS_d)

xxvi. Proportion of soil particles trapped in the body by inhalation (PIAF)

Refer to the relevant provisions of Britain, Holland, set 0.75.

xxvii. Reference dose distribution coefficient for soil exposure (SAF)

xxviii. Non-carcinogenic compounds are acceptable hazards (AHQ)

Refer to Europe and the United States (USEPA, 1996; RIVM, 1994), the recommended value of AHQ is 1.

xxix. Carcinogenic compounds have acceptable levels of carcinogenic risk (ACR)

A cancer risk of less than 1 in 10,000 (10^{-4}) is considered too small to be detected in the population, and is set at 10^{-6}-10^{-4} in Europe and the United States.

(2) Soil property parameter

The industrial site parameters are mainly referred to the recommended values in the American Society for Materials and Testing (ASTM,2002).

i. Soil bulk density (ρ_b, kg/dm^3)

The actual range of soil bulk density for residential and industrial land use in the United States is 1.25-1.75 kg/dm^3. The recommended value in American Society for Materials and Testing Standards (ASTM,2002) is 1.7 kg/dm^3.

ii. Soil particle density (ρ_s, kg/dm^3)

Refer to the U.S. Environmental Protection Agency to determine the recommended soil gravity value of 2.65.

iii. Soil moisture content (P_{ws})

The default parameter value of soil moisture content is set as 0.20, which is about the average level of sand soil moisture content and the lowest level of silt clay moisture content.

iv. Soil organic matter content (f_{om}, g/kg)

v. Width of soil contaminated area (W, cm)

The recommended value is 4500, which is determined by referring to ASTM (2010) for residential, commercial and industrial land use.

vi. Pore air volume ratio in unsaturated soil (θ_{avs})

The pore air volume ratio in unsaturated soil layer can be obtained by subtracting the pore water volume ratio from the total pore volume ratio in unsaturated soil layer.

vii. Pore water volume ratio in unsaturated soil (θ_{wvs})

The pore water volume ratio in unsaturated soil layer can be obtained from soil bulk density, soil moisture content and specific gravity of water.

$$\theta_{wvs} = \frac{\rho_b \times \rho_{ws}}{\rho_w}$$

viii. Total pore volume ratio in unsaturated soil (θ)

The total pore volume ratio in unsaturated soil layer can be obtained from soil bulk density and soil particle density.

$$\theta = 1 - \frac{\rho_b}{\rho_s}$$

ix. Distance from the upper surface to the surface of the underlying contaminated soil (L_s, cm)

This parameter is determined to be 100 according to the recommended parameter values in the American Society for Materials and Testing (ASTM,2002).

x. Mass fraction of soil organic carbon in vadose zone (f_{oc})

$$f_{oc} = f_{om}/1700$$

xi. Soil bulk density in vadose zone (ρ_b, kg/dm^3)

xii. Thickness of surface contaminated soil (d, cm)

Refer to the recommended parameter values in the ASTM standard (2002) and determine that the recommended value of the parameter is 100.

xiii. The thickness of the substratum contaminated soil (d_s, cm)

(3) Selection of physicochemical properties and toxicity parameters of pollutants

Countries	Residential land	Industrial and commercial land	Agricultural land
The United States	71	980	-
Britain	10	230	1.8
French	20	60	3
Canada	10	230	1.8
Taiwan	10	10	2.5

Table 7- Selection of physicochemical properties and toxicity parameters of pollutants

4.3 Determination of concentrations at the point of exposure

A receptor can be exposed to a compound at the source (direct exposure) or at a distance from it (indirect exposure): in the former case, the concentration that describes the source is the value that should be used in the RA; in the latter, the mechanisms of contaminant migration from the source to the POE have to be modeled. The modeling process develops in sequential steps, the output of each representing the input for the following.

Eventually, the process results in the determination of the natural attenuation factor (NAF), i.e., the ratio between the concentration of the COC at the source and at the POE (C_{POE}), in steady state conditions. The value of the NAF and, consequently, of C_{POE} depends on the specific migration oath followed by the contaminant.

4.3.1 Release in the Unsaturated Medium

Groundwater quality degradation starts with a spill from a source present in the soil and the subsequent formation.

Leachate is composed of a mix of compounds whose concentration is governed by the soil-leachate partition coefficient, K_{sw}. This parameter is defined as the ratio between the concentration of a generic component in the leachate and in the mass of soil at the source, in steady state conditions:

$$K_{sw} = \frac{C_{soil}}{C_{leach}} \quad (3.3.1)$$

Assuming that:

(a) The equilibrium between the concentrations in the leachate and in the soil at the source is achieved instantaneously;
(b) Decay processes in the soil and in the leachate are negligible;
(c) The mass present at the source is infinitely large relative to the release potential to the leachate;

The partition coefficient can be calculated from the total mass of the generic contaminant, M_T, contained in the volume, V_b, of the polluting source:

$$M_T = M_{leach} + M_s + M_g = (\theta_\omega + \rho_b K_d + H\theta_a) C_{leach} V_b \quad (3.3.2)$$

Thus, the concentration of the generic compound at the source is:

$$C_{soil} = \frac{M_T}{\rho_b V_b} = \frac{(\theta_\omega + \rho_b K_d + H\theta_a)}{\rho_b} C_{leach} \quad (3.3.3)$$

And the soil-leachate partition coefficient becomes:

$$K_{sw} = \frac{\theta_\omega + \rho_b K_d + H\theta_a}{\rho_b} \left[\frac{L^3}{M}\right] \quad (3.3.4)$$

where:

- ρ_b: *soil bulk density*;
- θ_ω: *volumetric water content*;
- θ_a: *volumetric air content, equaling to* $'n - \theta_\omega'$;
- n: *the total porosity*;
- H: *Henry'sconstant*;
- K_d: *the partition coefficient for organic compounds*;
- f_{oc}: *the fraction of organic carbon*;
- K_{oc}: *the partition coefficient of a compound between organic carbon and wat*

Based on expression (3.3.1) the concentration of an individual contaminant in the leachate is:

$$C_{leach} = \frac{C_{soil}}{K_{sw}} \quad (3.3.5)$$

Provided that it does not exceed the solubility limit:

$$C_{leach} \leq x_i S_i \quad (3.3.6)$$

where:

- x_i: *the molar fraction of a generic contaminant initially present at the sourc*
- S_i: *its solubility in water, and provided that the mass of the contaminant in th does not exceed, during the entire exposure duration*;
- ED: *the mass of the same contaminant at the source.*

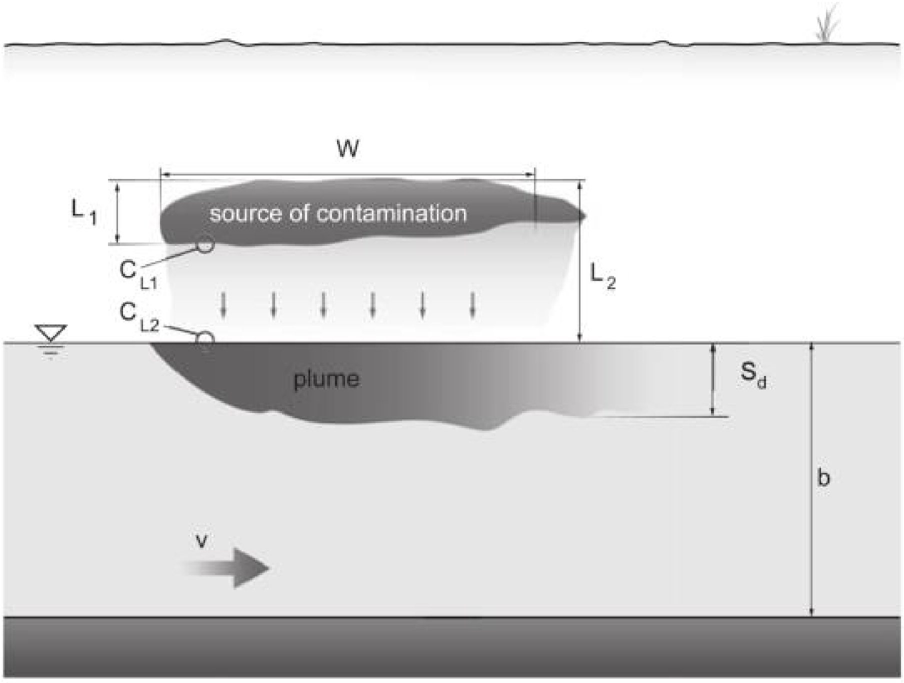


Figure 2- Schematic of release processes from the source to the water table

$$M_{leach} \leq M_{soil} \quad (3.3.7)$$

The latter condition translates into the inequality:

$$C_{leach} \cdot \left(I_{eff} \cdot ED\right) \cdot A \leq C_{soil} \cdot A \cdot L_1 \cdot \rho_b \quad (3.3.8)$$

or:

$$C_{leach} \leq \frac{C_{soil} \cdot L_1 \cdot \rho_b}{I_{eff} \cdot ED} \quad (3.3.9)$$

where:

- $I_{eff}: the\ effective\ infiltration\ occurring\ at\ the\ site\ of\ interest;$
- $L_1: thickness\ of\ the\ source\ of\ contamination;$
- $A: horziontal\ area\ of\ the\ source\ of\ contamination.$

Based on the above, the smallest value among those obtained from Eq. (3.3.5), (3.3.6) and (3.3.9) will clearly have to be used as C_{leach}.

Equation (3.3.4), describing the partition between the different phases at equilibrium, and representing the ASTM release model, is a very conservative solution that yields an overestimation of the leachate's composition, and hence of the RA. If leaching tests have been carried out, the experimental results can be directly used instead of Eq. (3.3.4).

In the case of RA of a solid waste landfill, this first step ends once the specific composition of the leachate, used as the starting datum for the procedure has been determined.

4.3.2 Attenuation in the Unsaturated Medium

Once the leachate is formed, it flows vertically towards the water table under the effect of gravity and of capillary forces. This flow causes the contaminant mass to spread across the volume of unsaturated medium that separates the source of contamination from the water table, resulting in a decrease in concentration.

If the depth to groundwater, L_2, is significantly greater than the thickness of the source of contamination, L_1, it is worth considering attenuation processes that may lead to a decrease in contaminant concentration as they cross the unsaturated zone. This decrease can be quantified through the so-called *Soil Attenuation Model (SAM)*.

If volatilization and biodegradation processes are neglected, and if the law of mass conservation is applied to each contaminant:

$$M_T = (\theta_\omega + \rho_b K_d + H\theta_a) \cdot C_{leach} \cdot A \cdot L = constant, \quad (3.3.10)$$

then:

$$C_{l2} = C_{l1}\frac{L_1}{L_2} \quad (3.3.11)$$

where:

- $C_{l1}: concentrations\ in\ the\ leachate\ at\ depth\ L_1;$
- $C_{l2}: concentrations\ in\ the\ leachate\ at\ depth\ L_2.$

C_{l2} represents, therefore, the maximum concentration of a contaminant when it reaches the water table. Actually, this value decreases in time, as the concentration of each compound at the source decreases. The SAM model, however, assumes that this concentration remains constant in time, consistently with the conservative assumption that the mass present at the source is infinitely greater than its release potential.

Even biodegradation, not considered until now, can play an important role during the migration of some organic compounds across thick unsaturated media. In this case, natural biodegradation can be simulated with an exponential decay model of the first order by using the dimensionless *Bio Degradation Factor, BDF*, which can be calculated as follows:

$$BDF = exp\left[-\lambda_v(L_2 - L_1)\frac{\theta_\omega + \rho_b K_d + H\theta_a}{I_{eff}}\right] \quad (3.3.12)$$

where:

- λ_v: $the\ biodegradation\ coefficient\ in\ the\ vadose\ zone, [T^{-1}]$.

If follows that the concentration of a contaminant in the leachate that mixes with groundwater can be expressed as:

$$C_{l2} = \frac{C_{soil}}{K_{sw} \cdot BDF} \cdot \frac{L_1}{L_2} \quad (3.3.13)$$

which can be reduced to:

$$C_{l2} = \frac{C_{soil}}{K_{sw} \cdot LAF} \quad (3.3.14)$$

by including all the attenuation factors that act on contaminants in the unsaturated medium in the Leachate Attenuation Factor (LAF). Clearly, overlooking the attenuation processes occurring in the unsaturated medium results in significantly more conservative results of the RA.

4.3.3 Leachate Dilution in the Mixing Zone

Once the leachate has crossed the entire unsaturated medium, it mixes with the groundwater at the water table.

At steady state a groundwater and leachate mixing zone is established, in which concentrations are diluted according to a dimensionless *Leachate Dilution Factor (LDF)*, defined as:

$$LDF = \frac{C_{l2}}{C_0} \quad (3.3.15)$$

where:

- C_0: $the\ contaminant\ concentration\ in\ the\ mixing\ zone\ below\ the\ source\ of\ contamination.$

A very simple conceptual model can be used to quantify the LDF, by evaluating the mass dilution in the mixing zone located right below the source of contamination.

Referring to the schematic and defining S_ω as the width of contamination front determined in the mixing zone perpendicularly to the direction of flow, S_d as the thickness of the mixing zone, v as the groundwater seepage velocity, and n_e as the effective porosity, the following can be derived:

- Leachate volume discharge entering the mixing zone,

$$I_{eff}\, W\, S_{\omega}$$

- Uncontaminated water volume discharge entering the mixing zone,

$$v\, n_e\, S_d\, S_{\omega}$$

- Overall liquid volume discharge present in the mixing zone.

$$v\, n_e\, S_d\, S_{\omega} + I_{eff}\, W\, S_{\omega} = (v\, n_e\, S_d + I_{eff}\, W)\, S_{\omega}$$

Consequently, the leachate dilution factor in the mixing zone (which is proportional to the discharge) is equal to:

$$LDF = 1 + \frac{v\, n_e\, S_d}{I_{eff}\, W} = 1 + \frac{K\, i\, S_d}{I_{eff}\, W} \quad (3.3.16)$$

where:

- $K: the\ hydraulic\ conductivity\ of\ the\ contaminated\ aquifer;$
- $i: the\ average\ pirzometric\ gradient\ in\ the\ mixing\ zone;$
- $W: the\ width\ of\ the\ source\ along\ the\ direction\ of\ flow.$

A correct estimation of the thickness, S_d, of the mixing zone is not straightforward. If a specific estimate is not available, the following algorithm can be used:

$$S_d = \sqrt{2\alpha_z\, W} + b \cdot \left[1 - e^{-\frac{I_{eff} \cdot W}{K \cdot i \cdot b}}\right] \quad (3.3.17)$$

where:

- $b: the\ saturated\ thickness\ of\ the\ aquifer;$
- $\alpha_z: the\ vertical\ dispersivity, provided\ that\ S_d \leq b.$

To summarize, the concentration of a contaminant in the mixing zone of an aquifer can be derived from its concentration at the source by applying the following expression:

$$C_0 = \frac{C_{soil}}{LAF \cdot K_{sw} \cdot LDF} \quad (3.3.18)$$

If monitoring wells have been installed and used to sample contaminated groundwater from the aquifer, below the source, and if the concentration distribution can be considered to have reached a steady state relative to the duration of the phenomenon, the measured concentration values can be used instead of the above described calculations. Thus, they become the starting values of the RA.

4.3.4 Dilution and Attenuation in the Aquifer

The aquifer contamination that occurred in the mixing zone due to the leachate that percolated from the source of contamination in the soil is further diluted and attenuated due to transport and dispersion phenomena in the aquifer itself.

This decrease in concentration is quantified through is quantified through the dimensionless *Dilution Attenuation Factor (DAF)*, defined as the ratio between the concentration of the compound in the mixing zone, C_0, and in the aquifer, downgradient of the mixing zone, C_{gw}:

$$DAF = \frac{C_0}{C_{gw}} \quad (3.3.19)$$

The DAF can be determined analytically or numerically.

Domenico's is one of the most commonly used analytical solutions, due to the fact that it applies to boundary conditions that describe with sufficient accuracy the dispersion of a compound released from a source of non-negligible dimensions via continuous injection. This solution describes the non-steady three-dimensional concentration distribution resulting from a continuous release from a plane source positioned perpendicularly to the direction of flow of the aquifer, with transversal and vertical dimensions, $S_w$and S_d, respectively.

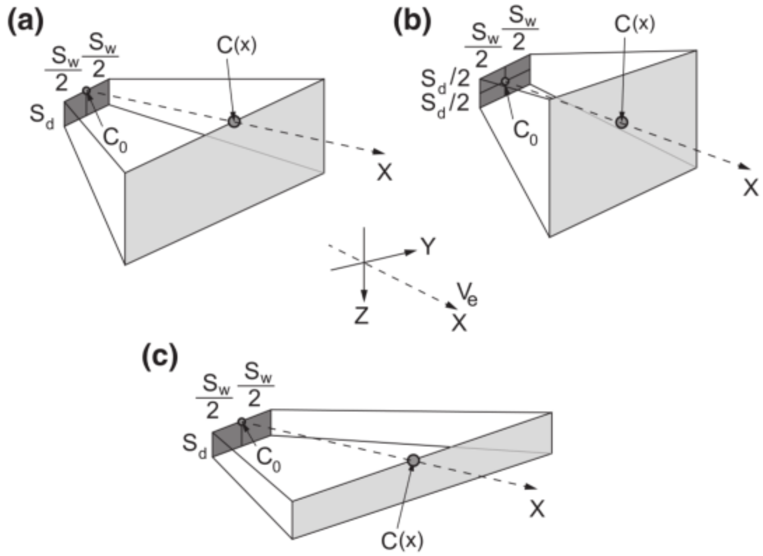


Figure 3- Possible effects of vertical dispersion on the geometry of contamination resulting from the continuous release from a plane source: (a) only downward-directed vertical dispersion; (b) vertical dispersion directed both up-and down-ward; (c) no vertical dispersion (the contaminant reached the base of the aquifer in the mixing zone)

In addition to the hydrological processes, the solution accounts for the potential natural decay of a contaminant, which can be described with a first order reaction kinetics, and for potential sorption of the contaminant to the surface of the solid grains, which can be described by a linear isotherm.

In the more realistic hypothesis that contaminant dispersion occurs along two transverse and one vertical direction, as well as along the direction of flow, x, if we indicate with C_0 the concentration at the plane source, with α_x, α_y and α_z, respectively, the longitudinal, transverse and vertical dispersity, with R_i the retardation factor of a generic compound, and with λ_i its decay coefficient, in steady state conditions the highest concentration value will be found along the x axis:

$$\frac{C(x)}{C_o} = exp\left\{\left(\frac{x}{2\alpha_x}\right)\left[1 - \sqrt{1 + \frac{4\lambda_i \alpha_x R_i}{v}}\right]\right\} \cdot erf\left[\frac{S_w}{4\sqrt{\alpha_y x}}\right] \cdot erf\left[\frac{S_d}{2\sqrt{\alpha_z x}}\right] \quad (3.3.20)$$

Here degradation is assumed to occur both in the liquid and in the sorbed phase.

Should the inclusion of both directions of vertical dispersion be preferable for the contaminant at hand, analogously to the two transverse directions, Eq. (3.20) becomes:

$$\frac{C(x)}{C_o} = exp\left\{\left(\frac{x}{2\alpha_x}\right)\left[1 - \sqrt{1 + \frac{4\lambda_i \alpha_x R_i}{v}}\right]\right\} \cdot erf\left[\frac{S_w}{4\sqrt{\alpha_y x}}\right] \cdot erf\left[\frac{S_d}{2\sqrt{\alpha_z x}}\right] \quad (3.3.21)$$

Finally, if the aquifer thickness is small and entirely affected by the contamination since the mixing phase, there will be no vertical dispersion and Eq. (3.20) becomes:

$$\frac{C(x)}{C_o} = exp\left\{\left(\frac{x}{2\alpha_x}\right)\left[1 - \sqrt{1 + \frac{4\lambda_i \alpha_x R_i}{v}}\right]\right\} \cdot erf\left[\frac{S_w}{4\sqrt{\alpha_y x}}\right] \quad (3.3.22)$$

Since $C(x)$ is the highest contaminant concentration that can be found in the aquifer downgradient of the mixing stage, in the procedure to calculate risk, C_{gw} is set equal to $C(x)$.

When the above described boundary conditions and/or the geometry of the source of contamination are not suitable to describe the real system, the differential equation must be solved numerically to describe the hydrologic, physico-chemical and biological processes involved in the event under investigation.

Whatever the approach eventually used, the dispersivity parameters play an important role; these are, however, difficult to determine experimentally. If specific values are not available, conservative values recommended by default by the RBCA approach are:

$$\alpha_x = 0.1L,$$
$$\alpha_y = 0.33\alpha_x,$$
$$\alpha_z = 0.05\alpha_x,$$

Many correlations for the estimation of dispersivity parameters according to the scale, L, of the examined event are available.

4.3.5 Dilution in a River

If the considered aquifer is drained by a river, as depicted in Fig.3, the hypothetical groundwater contamination undergoes an additional dilution process, quantified by the dimensionless *River Dilution Factor* (*RDF*, or groundwater to surface water dilution factor). The *RDF* is defined as the ratio between the contaminant concentration in the groundwater upgradient of the mixing zone with the river, C_F, and its concentration in the river, C_r:

$$RDF = \frac{C_{gw}}{C_r} \quad (3.3.23)$$

If we refer to the schematic in Fig.3, *RDF* can be calculated via the discharge balance in the mixing zone, through the following equation:

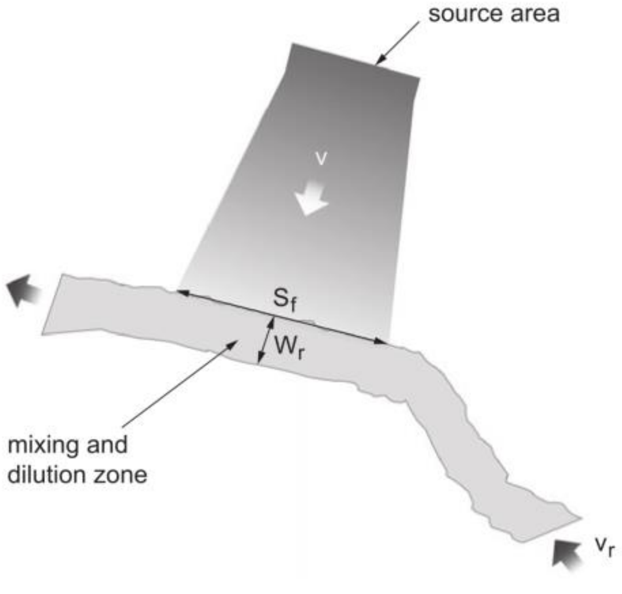


Figure 4- Contamination plume dilution in a river

$$RDF = 1 + \frac{Q_r}{v\, n_e\, S_f\, b_r} = 1 + \frac{v_r\, W_r}{v\, n_e\, S_f} \quad (3.3.24)$$

where:

- $b_r: the\ width\ of\ groundwater - to - surface\ water\ discharge;$
- $Q_r: the\ river\ discharge\ in\ dry\ spell\ conditions;$
- $v_r: the\ river\ water\ velocity\ in\ dry\ spell\ conditions;$
- $W_r: the\ river\ width\ in\ dry\ spell\ conditions.$
- $S_f: the\ thickness\ of\ affected\ groundwater\ to\ surface\ water\ discharge.$

Equation (3.3.24) is applicable if the contaminant concentration in the river (C_{r0}) upstream of the mixing area is equal to 0.

If, instead, $C_{r0} \neq 0$, the *RDF* is equal to:

$$RDF = \frac{C_{gw}[v\, n_e\, S_f\, b + Q_r]}{C_{gw}\ v\, n_e\, S_f\, b + C_{r0} Q_r} = \frac{C_{gw}[v\, n_e\, S_f + v_r W_r]}{C_{gw}\, v\, n_e\, S_f + C_{r0}\, v_r\, W_r} \quad (3.3.25)$$

4.3.6 Vapor Volatilization in Outdoor Environments

Volatile compounds present in the groundwater can migrate across the unsaturated zone and towards the surface as vapors (Fig.3(a)). In outdoor environments, vapors mix with the air above the source of contamination. The process can be described quantitatively through the dimensionless outdoor Volatilization Factor ($V\,F_{out}$), defined as the ratio between the contaminant concentration in the atmosphere at the POE, C_{POE}, and its concentration in the groundwater, C_F:

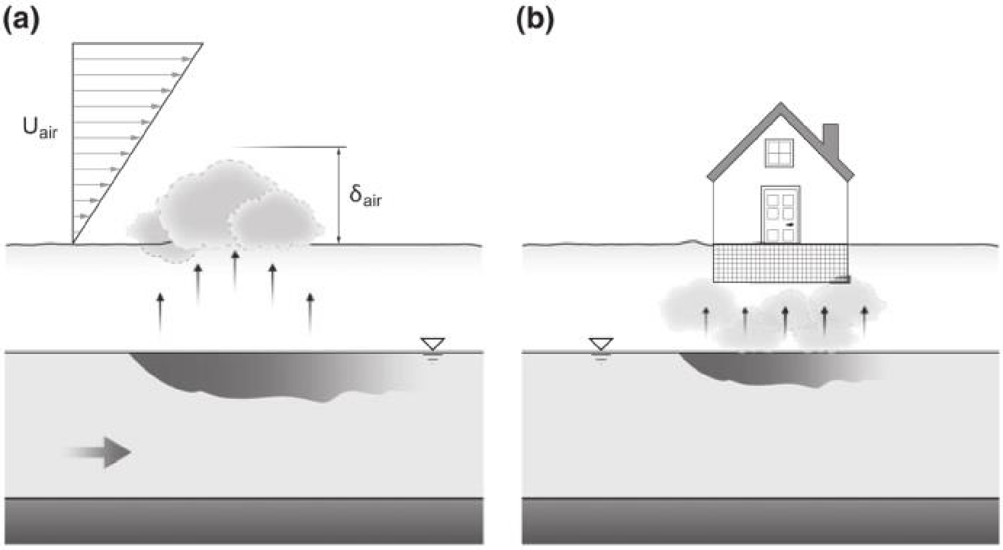


Figure 5- Vapor volatilization in out-and in-door environments

$$V\,F_{out} = \frac{C_{POE}}{C_F} \quad (3.3.26)$$

$V\,F_{out}$ can be estimated with the following equation:

$$V\,F_{out} = \frac{H}{1 + \frac{U_{air}\delta_{air}L_{GW}}{D_{ws}^{eff}\,W'}} \cdot 10^3 \quad (3.3.27)$$

- U_{air}: *the average air velocity* $2m$ *above the surface*;
- δ_{air}: *the elevation of the mixing zone in the atmosphere*;
- L_{GW}: *the depth to groundwater*;
- W': *the length of the source in the main wind direction*;
- D_{ws}^{eff}: *the figgusion coefficient of the contaminant, expressed as a function o characteristics of the capillary fringe and of the vadose zone*

.

$$D_{ws}^{eff} = \left(h_{cap} + h_v\right) \cdot \left(\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}}\right)^{-1} \quad (3.3.28)$$

where:

- h_{cap}: *the thickness of the capillary fringe*;
- h_v: *the thickness of the unsaturated zone*;
- D_{cap}^{eff}: *the effective diffusion coefficient in the capillary fringe*.

The latter parameter can be expressed as:

$$D_{cap}^{eff} = D_a \cdot \frac{\theta_{a,cap}^{3.33}}{n^2} + \frac{D_w}{H} \cdot \frac{\theta_{w,cap}^{3.33}}{n^2} \quad (3.3.29)$$

where:

- D_s^{eff}: *the effecitve diffusion coefficient in the unsaturated zone*;

$$D_s^{eff} = D_a \cdot \frac{\theta_a^{3.33}}{n^2} + \frac{D_w}{H} \cdot \frac{\theta_w^{3.33}}{n^2} \quad (3.3.30)$$

where:

- D_a: *the diffusion coefficient in air*;
- D_w: *the diffusion coefficient in water*;
- $\theta_{a,cap}$: *the air content in the capillary fringe*;
- $\theta_{w,cap}$: *the water content in the capillary fringe*.

4.3.7 Vapor Volatilization in Indoor Environments

Volatilization in indoor environments occurs when there is a building above the contaminated portion of the aquifer. The volatile fraction of contaminants can infiltrate within buildings through cracks in the foundations or walls (Fig. 3(b)). This phenomenon is quantitatively described by the dimensionless indoor Volatilization Factor, $V\,F_{in}$, defined as the ratio between the contaminant concentration in indoor air at the POE, C_{POE}, and in the aquifer, C_F:

$$V\,F_{in} = \frac{C_{POE}}{C_F} \quad (3.3.31)$$

A model proposed by Johnson e Ettinger is used to estimate $V\,F_{in}$:

$$V\,F_{in} = \frac{H\dfrac{D_w^{eff}}{L_{GW}L_bER}}{1+\dfrac{D_w^{eff}}{L_{GW}L_bER}+\dfrac{D_w^{eff}L_{crack}}{D_{crack}^{eff}L_{GW}\eta}} \quad (3.3.32)$$

where:

- $L_b: the\ ratio\ between\ indoor\ volume\ and\ infiltration\ surface\ area;$
- $ER: the\ indoor\ air\ circulation\ rate;$
- $L_{crack}: the\ thickness\ of\ the\ foundations;$
- $\eta: the\ surface\ fraction\ of\ the\ cracks\ in\ the\ foundations;$
- $D_{crack}^{eff}: the\ effective\ diffusion\ coefficient\ of\ the\ contaminant\ through\ the\ cr$

D_{crack}^{eff} is expressed by the following equation:

$$D_{crack}^{eff} = D_a\cdot\frac{\theta_{a,crack}^{3.33}}{n^2}+\frac{D_w}{H}\cdot\frac{\theta_{w,crack}^{3.33}}{n^2} \quad (3.3.33)$$

In the previous equation $\theta_{a,crack}$ and $\theta_{w,crack}$ are the air and water content in the cracks of the foundations, respectively.

4.3.8 Overall Attenuation Factor

The degradation of water resources undergoes an overall attenuation measured by the *Natural Attenuation Factor (NAF)*, defined as:

$$NAF = \frac{contaminant\ concentration\ at\ the\ source}{contaminant\ concentration\ at\ the\ point\ of\ exposure}$$

$$= \frac{C_{soil}}{C_{POE}} \quad (3.3.34)$$

Based on the previous paragraphs, if exposure by ingestion of contaminated water is considered, the value of the NAF can be derived from the following:

$$NAF = K_{sw} \cdot LAF \cdot LDF \cdot DAF \cdot RDF \quad (3.3.35)$$

Dimensionally, $NAF = [L^3/M]$.

Clearly, if exposure does nor occur via water taken from a river, but directly from an aquifer, RDF can be set equal to 1 in Eq. (3.35).

If, instead, exposure occurs by inhalation of vapors migrating from the groundwater, the NAF can be calculated as,

$$NAF = \frac{K_{sw} \cdot LAF \cdot LDF}{V\ F} \quad (3.3.36)$$

Where $V\ F = V\ F_{out}$ if exposure happens outdoors, or $V\ F = V\ F_{in}$ if it happens indoors.

4.3.9 Concentration at the Point of Exposure

Based on the definition of the natural attenuation factor, which summarizes all the attenuation mechanisms that could occur during the migration of the contaminants from the source to the point of exposure, the concentration at the POE is:

$$C_{POE} = \frac{C_{soil}}{NAF} \quad (3.3.37)$$

If a monitoring network is available at the point of exposure to measure the concentrations of the groundwater contaminants, these values can be used directly to determine of the resulting health risk. In this case, risk assessment will be more reliable because all uncertainties associated with the simulation of complex physical, chemical and biological processes influencing the transport and spreading of the contamination are eliminated.

4.4 Actual risk calculation

The human health risk represents the risk increment the receptor is subjected to as a result of the exposure to a specific situation of environmental contamination. The value of risk is clearly correlated to the concentration value of the contaminant at the POE, the exposure rate and the toxicological features of the compound.

It includes the Exposure assessment, Definition of the toxicological model and Toxic and carcinogenic risk calculation.

4.4.1 Exposure assessment

The risk assessment procedure entails the identification of all the actual migration paths that COCs can follow to reach the POE. Exposure of the receptor can occur at the source of contamination or at a certain distance from it. In the former case, (direct exposure), the concentration of the contaminant at the point of compliance coincides with the concentration assumed as representative of the source. Conversely, indirect exposure can only be calculated by modeling the mechanisms that drive contaminant migration from the source to the point of compliance.

4.4.2 Definition of the toxicological model and toxic and carcinogenic risk calculation

（1） Toxic effect of pollutants

The harmful effects of different ways of pollutants on human health were analyzed, including carcinogenic effect, non-carcinogenic effect, harmful mechanism and dose-effect relationship of pollutants on human health.

（2） Determine contaminant-related parameters

i. Carcinogenic effect toxicity parameters

Carcinogenic effect toxicity parameters include respiratory inhalation unit carcinogenic factor （ IUR ） respiratory inhalation carcinogenic slope factor（SF_i）、oral ingestion carcinogenic slope factor（SF_o）and skin contact carcinogenic slope factor（SF_d）.

Respiratory inhalation carcinogenic slope factor（SF_i）was extrapolated from respiratory inhalation unit carcinogenic factor（IUR）. Skin contact oncogenic slope factor（SF_d）was extrapolated from oral ingestion oncogenic slope factor（SF_o）as shown in formula (3.4.1) and Formula (3.4.2) below.

$$SF_i = \frac{IUR \times BW_a}{DAIR_a} \quad (3.4.1)$$

- SF_i: Respiratory inhalation carcinogenic slope factor;
- IUR: Respiratory inhalation unit carcinogenic factor;
- BW_a: Adult weight，kg;
- $DAIR_a$: Adult daily air volume，$mg \cdot m^{-3}$.

$$SF_d = \frac{SF_o}{ABS_{gi}} \quad (3.4.1)$$

- SF_d: Skin contact carcinogenic slope factor;
- SF_o: Oral ingestion of carcinogenic slope factor;
- ABS_{gi}: Digestive tract respiratory efficiency factor.

ii. **Noncarcinogenic effect toxicity parameters**

These include respiratory inhalation reference concentration （RfC）, respiratory inhalation reference dose（RfD_i）, oral intake reference dose（RfD_o）and dermal contact reference dose（RfD_d）。

The respiratory inhalation reference dose（RfD_i）was extrapolated from the respiratory inhalation reference concentration（RfC）. Skin contact reference dose（RfD_d）was extrapolated from oral ingestion reference dose （RfD_o）.The recommended models for extrapolating RfD_i and RfD_d are shown in Formula (3.4.3) and Formula (3.4.4), respectively.

$$RfD_i = \frac{RFC \times DAIR_a}{BW_a} \quad (3.4.3)$$

- RfD_i: Respiratory inhalation reference dose;
- RFC: Respiratory inhalation reference concentration；
- $DAIR_a$: Adult daily air volume，$mg \cdot m^{-3}$.
- BW_a: Adult weight，kg；

$$RfD_d = RfD_o \times ABS_{gi} \quad (3.4.3)$$

- RfD_d: Skin contact reference dose;
- RfD_o: Oral intake reference measurement;
- ABS_{gi}: Digestive tract absorption efficiency factor.

iii. **Physical and chemical properties of pollutants**

The physical and chemical properties of pollutants required for risk assessment include dimensionless Henry's constant （H'）、Diffusion coefficient in air（D_a）、Diffusion coefficient in water（D_w）、Soil organic carbon distribution coefficient （K_{oc}）、Solubility in water（S）。

iv. **Other related parameters of pollutants**

Other relevant parameters include digestive tract absorption factor（ABS_{gi}）、Skin absorption factor（ABS_d）and oral absorption factor（ABS_o）.

4.5Decision Assessment

This part includes the Uncertainty analysis, the Risk acceptability assessment and the Limit concentration calculation at the source of contamination.

4.5.1 Uncertainty analysis

The main sources of uncertainty in the risk assessment results of contaminated sites should be analyzed, including exposure scenario hypothesis, applicability of assessment model, model parameter value and so on.

（1） **Analysis of exposure risk contribution rate**

The analysis and recommendation models of carcinogenic risk and hazard quotient contribution rate of single pollutant through different exposure channels are shown in Formula (3.5.1) and Formula (3.5.2) respectively.

$$PCR_i = \frac{CR_i}{CR_n} \times 100\% \quad (3.5.1)$$

$$PHQ_i = \frac{HQ_i}{HI_n} \times 100\% \quad (3.5.2)$$

- CR_i: Carcinogenic risk of single pollutant through type I exposure pathway；
- CR_n: Total carcinogenic risk of NTH single pollutant in soil through all exposure pathways；
- PCR_i: Contribution of single pollutant to carcinogenic risk through the i-th exposure pathway；
- HQ_i: Hazard quotient of single pollutant through I exposure route；
- HQ_n: Hazard index of single pollutant through NTH exposure route；
- PHQ_i: Contribution of non-carcinogenic risk of single pollutant via i-type exposure pathway.

The larger the percentage calculated according to the above formula, the higher the contribution rate of a specific exposure route to the total risk.

（2） **Sensitivity analysis of model parameters**

i. Principle of determining sensitive parameters

Selected the need for sensitivity analysis of parameters (P) in general should be a greater influence on the calculation result of risk parameters, such as population related parameters (weight, exposure, exposure frequency, etc.), and exposure pathways related parameters (the daily dose of soil, the skin surface soil adhesion coefficient, the daily intake air volume, interior space volume and vapor infiltration area ratio, etc.). When the risk contribution rate of a single exposure pathway exceeds 20%, sensitivity analysis of the population and parameters related to the pathway should be performed。

ii. Sensitivity analysis method

The sensitivity of model parameters can be expressed by the sensitivity ratio, that is, the ratio of the change in model parameter values (from P1 to P2) to the change in carcinogenic risk or hazard quotient (from X1 to X2).The recommended model for calculating sensitivity ratio is shown in Formula (3.5.3).

$$SR = \frac{\frac{X_2 - X_1}{X_1}}{\frac{P_2 - P_1}{P_1}} \times 100\% \quad (3.5.3)$$

- SR: Sensitivity ratio of model parameters；
- P_1: The value before the change of model parameter P；
- P_2: The value of model parameter P after change；
- X_1: Carcinogenic risk or hazard quotient calculated at P_1；
- X_2: Carcinogenic risk or hazard quotient calculated at P_2。

The greater the sensitivity ratio, the greater the influence of this parameter on the risk. In the sensitivity analysis of model parameters, the variation range of parameter values should be determined by considering the actual value range of parameters.

4.5.2 Risk acceptability evaluation

(1) Acceptable carcinogenic risk and hazard quotient

In the calculation of soil and groundwater risk control values based on carcinogenic effects, the acceptable carcinogenic risk of a single pollutant used in this code is 10-6; When calculating soil and groundwater risk control values based on non-carcinogenic effects, the acceptable hazard quotient for a single pollutant is 1.

(2) Calculate site soil and groundwater risk control values

i. Soil risk control values based on carcinogenic effects

For a single pollutant, calculation based on oral intake of soil, and soil particles, the inhalation and skin contact gaseous pollutants from surface soil in the outdoor air, outdoor air inhaled from the subsoil of gaseous pollutants, in indoor air inhaled from the subsoil gaseous pollutants exposure ways of carcinogenic effect of soil recommendation model of risk control values. See formulas (3.5.4), (3.5.5), (3.5.6), (3.5.7), (3.5.8) and (3.5.9), respectively. The recommended model to calculate the soil risk control values of single pollutant based on the carcinogenic effects of the above six soil exposure pathways is shown in Formula (3.5.10)

$$RCVS_{ois} = \frac{ACR}{OISER_{ca} \times SF_o} \quad (3.5.4)$$

- $RCVS_{ois}$: Soil risk control values based on carcinogenic effects of oral ingestion pathway；
- ACR: Acceptable risk of cancer；
- $OISER_{ca}$: Soil exposure through oral ingestion (carcinogenic effect)；
- SF_o: Oral intake of reference dose；

$$RCVS_{dcs} = \frac{ACR}{DCSER_{ca} \times SF_d} \quad (3.5.5)$$

- $RCVS_{dcs}$: Soil risk control values based on carcinogenic effects of skin contact pathways；
- $DCSER_{ca}$: Soil exposure by skin contact route (carcinogenic effect)；
- SF_d: Skin contact carcinogenic slope factor；

$$RCVS_{pis} = \frac{ACR}{PISER_{ca} \times SF_i} \quad (3.5.6)$$

- $RCVS_{pis}$: Soil risk control values based on carcinogenic effects of inhaled soil particulate pathways；
- $PISER_{ca}$: Soil exposure to inhaled soil particulate matter (carcinogenic effect)；
- SF_i: Respiratory inhalation carcinogenic slope factor；

$$RCVS_{iov\,1} = \frac{ACR}{IOVER_{ca\,1} \times SF_i} \quad (3.5.7)$$

- $RCVS_{iov\,1}$: Soil risk control values based on carcinogenic effects of gaseous pollutant pathways from topsoil in inhaled outdoor air；
- $IOVER_{ca\,1}$: Inhalation of outdoor air corresponds to soil exposure to gaseous pollutants from topsoil；

$$RCVS_{iov\,2} = \frac{ACR}{IOVER_{ca\,2} \times SF_i} \quad (3.5.8)$$

- $RCVS_{iov\,2}$: Soil risk control values for carcinogenic effects of gaseous pollutant pathways from subsoil based on inhalation of outdoor air；
- $IOVER_{ca\,2}$: Soil exposure to gaseous pollutants from the underlying soil from inhalation of outdoor air (carcinogenic effect)；

$$RCVS_{iiv} = \frac{ACR}{IIVER_{ca\,1} \times SF_i} \quad (3.5.9)$$

- $RCVS_{iiv}$: Soil risk control values based on carcinogenic effects of gaseous pollutant pathways from subsoil in inhaled indoor air；
- $IIVER_{ca\,1}$: Soil exposure to gaseous pollutants from subsoil in inhaled indoor air (carcinogenic effect)；

$$RCVS_n = \frac{ACR}{OISER_{ca} \times SF_o + DCSER_{ca} \times SF_d + (PISER_{ca} + IOVER_{ca\,1} + IOVER_{ca\,2} + IIVER_{ca\,1}) \times SF_i}$$

（3.5.10）

- $RCVS_n$: Soil risk control values for single pollutant (NTH) based on the combined carcinogenic effects of six soil exposure pathways；
- ACR: Acceptable risk of cancer；
- $OISER_{ca}$: Soil exposure through oral ingestion (carcinogenic effect）；
- $DCSER_{ca}$: Soil exposure by skin contact route (carcinogenic effect)；
- $PISER_{ca}$: Soil exposure to inhaled soil particulate matter (carcinogenic effect)；
- $IOVER_{ca\,1}$: Inhalation of outdoor air corresponds to soil exposure to gaseous pollutants from topsoil；
- $IOVER_{ca\,2}$: Soil exposure to gaseous pollutants from the underlying soil from inhalation of outdoor air (carcinogenic effect)；
- $IIVER_{ca\,1}$: Soil exposure to gaseous pollutants from subsoil in inhaled indoor air (carcinogenic effect)；
- SF_o: Oral intake of reference dose；
- SF_d: Skin contact carcinogenic slope factor；
- SF_i: Respiratory inhalation carcinogenic slope factor。

ii. <u>Soil risk control values based on non-carcinogenic effects</u>

For a single pollutant, calculation based on oral intake of soil, and soil particles, the inhalation and skin contact kinds of gaseous pollutants from surface soil, outdoor air inhaled from the subsoil in the outdoor air gaseous pollutants, in indoor air inhaled from the subsoil of gaseous pollutants exposure ways of carcinogenic effect of soil recommendation model of risk control values. See formulas (3.5.11), (3.5.12), (3.5.13), (3.5.14), (3.5.15) and (3.5.16), respectively. The recommended model for calculating the soil risk control values of a single pollutant based on the non-carcinogenic effects of the above six soil exposure pathways is shown in Formula (3.5.17).

$$HCVS_{ois} = \frac{RfD_o \times SAF \times AHQ}{OISER_{nc}} \quad （3.5.11）$$

- $HCVS_{ois}$: Soil risk control values based on non-carcinogenic effects of oral ingestion;
- RfD_o: Oral intake reference measurement；
- AHQ: Acceptable hazard merchant；
- SAF: A reference dose distribution system for soil exposure；
- $OISER_{nc}$: Soil exposure through oral ingestion (non-carcinogenic effect)；

$$HCVS_{dcs} = \frac{RfD_d \times SAF \times AHQ}{DCSER_{nc}} \quad （3.5.12）$$

- $HCVS_{dcs}$: Soil risk control values based on non-carcinogenic effects of skin contact with soil;
- RfD_d: Skin contact reference dose;
- AHQ: Acceptable hazard merchant；
- SAF: A reference dose distribution system for soil exposure;
- $DCSER_{nc}$: Soil exposure by skin contact route (non-carcinogenic effect).

$$HCVS_{pis} = \frac{RfD_i \times SAF \times AHQ}{PISER_{nc}} \quad （3.5.13）$$

- $HCVS_{pis}$: Soil risk control values based on non-carcinogenic effects of soil particulate pathways inhaled;
- RfD_i: Respiratory inhalation reference dose；
- AHQ: Acceptable hazard merchant；
- SAF: A reference dose distribution system for soil exposure；
- $PISER_{nc}$: Soil exposure to inhaled soil particulate matter (non-carcinogenic effect)；

$$HCVS_{iov\,1} = \frac{RfD_i \times SAF \times AHQ}{IOVER_{nc\,1}} \quad （3.5.14）$$

- $HCVS_{iov\,1}$: Soil risk control values based on non-carcinogenic effects of gaseous pollutant pathways from topsoil in inhaled outdoor air;

- RfD_i: Respiratory inhalation reference dose;
- AHQ: Acceptable hazard merchant;
- SAF: A reference dose distribution system for soil exposure;
- $IOVER_{nc\,1}$: Soil exposure to gaseous pollutants from topsoil from inhalation of outdoor air (non-carcinogenic effect);

$$HCVS_{iov\,2} = \frac{RfD_i \times SAF \times AHQ}{IOVER_{nc\,2}} \quad (3.5.15)$$

- $HCVS_{iov\,2}$: Soil risk control values based on non-carcinogenic effects of gaseous pollutant pathways from subsoil in inhaled outdoor air;
- RfD_i: Respiratory inhalation reference dose;
- AHQ: Acceptable hazard merchant;
- SAF: A reference dose distribution system for soil exposure;
- $IOVER_{nc\,2}$: Soil exposure to gaseous pollutants from the underlying soil from inhalation of outdoor air (non-carcinogenic effect);

$$HCVS_{iiv} = \frac{RfD_i \times SAF \times AHQ}{IIVER_{nc\,1}} \quad (3.5.16)$$

- $HCVS_{iiv}$: Soil risk control values based on non-carcinogenic effects of gaseous pollutant pathways from subsoil in inhaled indoor air;
- RfD_i: Respiratory inhalation reference dose;
- AHQ: Acceptable hazard merchant;
- SAF: A reference dose distribution system for soil exposure;
- $IIVER_{nc\,1}$: Soil exposure to gaseous pollutants from subsoil in inhaled indoor air (non-carcinogenic effect);

$$HCVS_n = \frac{AHQ \times SAF}{\frac{OISER_{nc}}{RfD_o} + \frac{DCSER_{nc}}{RfD_d} + \frac{PISER_{nc} + IOVER_{nc\,1} + IOVER_{nc\,2} + IIVER_{nc\,1}}{RfD_i}} \quad (3.5.17)$$

- $HCVS_n$: Soil risk control values for a single pollutant (NTH) based on the combined non-carcinogenic effects of six soil exposure pathways;
- RfD_i: Respiratory inhalation reference dose;
- RfD_o: Oral intake reference measurement;
- RfD_d: Skin contact reference dose;
- AHQ: Acceptable hazard merchant;
- SAF: A reference dose distribution system for soil exposure;
- $OISER_{nc}$: Soil exposure through oral ingestion (non-

carcinogenic effect)；

- $DCSER_{nc}$: Soil exposure by skin contact route (non-carcinogenic effect);
- $PISER_{nc}$: Soil exposure to inhaled soil particulate matter (non-carcinogenic effect);
- $IOVER_{nc\,1}$: Soil exposure to gaseous pollutants from topsoil from inhalation of outdoor air (non-carcinogenic effect)
- $IOVER_{nc\,2}$: Soil exposure to gaseous pollutants from the underlying soil from inhalation of outdoor air (non-carcinogenic effect);
- $IIVER_{nc\,1}$: Soil exposure (non-carcinogenic effect) to gaseous pollutants from subsoil in inhaled indoor air.

iii. Soil risk control values for protecting groundwater

When the groundwater of polluted site is used as drinking water source, the soil risk control value of protecting groundwater should be calculated. For a single pollutant, the recommended model for calculating soil risk control values for protecting groundwater is shown in the formula（3.5.18）。

$$CVS_{pgw} = \frac{MCL_{gw}}{LF_{sgw}} \quad (3.5.18)$$

- CVS_{pgw}: Soil risk control values for protecting groundwater；
- MCL_{gw}: The maximum concentration limits of groundwater pollutants；
- LF_{sgw}: Leaching factors of soil pollutants into groundwater。

iv. Groundwater risk control values based on carcinogenic effects

For a single pollutant, the recommended models for groundwater risk control values based on gaseous pollutants inhaled from groundwater in outdoor air, gaseous pollutants inhaled from groundwater in indoor air, and carcinogenic effects of groundwater exposure pathways are shown in Formulas (3.5.19) (3.5.20) and (3.5.21) respectively. The recommended model to calculate the groundwater risk control value of single pollutant based on the carcinogenic effect of the above three groundwater exposure pathways is shown in formula (3.5.22)

$$RCVG_{iov} = \frac{ACR}{IOVER_{ca\,3} \times SF_i} \quad (3.5.19)$$

- $RCVG_{iov}$: Groundwater risk control values based on carcinogenic effects of gaseous pollutant pathways from groundwater in inhaled outdoor air;

- ACR: Acceptable risk of cancer;
- $IOVER_{ca\,3}$: Groundwater exposure corresponding to gaseous pollutants from groundwater inhaled in outdoor air (carcinogenic effect);
- SF_i: Respiratory inhalation carcinogenic slope factor;

$$RCVG_{iiv} = \frac{ACR}{IIVER_{ca\,2} \times SF_i} \quad (3.5.20)$$

- $RCVG_{iiv}$: Groundwater risk control values based on carcinogenic effects of gaseous pollutant pathways from groundwater in inhaled indoor air;
- ACR: Acceptable risk of cancer;
- $IIVER_{ca\,2}$: Groundwater exposure to gaseous pollutants from groundwater in inhaled indoor air (carcinogenic effect);
- SF_i: Respiratory inhalation carcinogenic slope factor;

$$RCVG_{cgw} = \frac{ACR}{CGWER_{ca} \times SF_o} \quad (3.5.21)$$

- $RCVG_{cgw}$: Groundwater risk control values based on carcinogenic effects of groundwater access;
- ACR: Acceptable risk of cancer;
- $CGWER_{ca}$: Exposure to groundwater corresponding to drinking affected groundwater (carcinogenic effect);
- SF_o: Oral intake of reference dose;

$$RCVG_n = \frac{ACR}{(IOVER_{ca\,3} + IIVER_{ca\,2}) \times SF_i + CGWER_{ca} \times SF_o} \quad (3.5.22)$$

- $RCVG_n$: Groundwater risk control values for single pollutant (NTH) based on the combined carcinogenic effects of three groundwater exposure pathways;
- ACR: Acceptable risk of cancer;
- $IOVER_{ca\,3}$: Groundwater exposure to gaseous pollutants from groundwater inhaled in outdoor air (carcinogenic effect);
- SF_i: Respiratory inhalation carcinogenic slope factor;
- $IIVER_{ca\,2}$: Groundwater exposure to gaseous pollutants from groundwater in inhaled indoor air (carcinogenic effect);
- $CGWER_{ca}$: Exposure to groundwater corresponding to drinking affected groundwater (carcinogenic effect);
- SF_o: Oral intake reference dose;

v. Groundwater risk control values based on non-carcinogenic effects

For a single pollutant, the recommended models for groundwater risk control values based on gaseous pollutants inhaled from groundwater in outdoor air, gaseous pollutants inhaled from groundwater in indoor air, and non-carcinogenic effects of groundwater exposure are shown in Formulas (3.5.23), (3.5.24), and (3.5.25) respectively. The recommended model to calculate the groundwater risk control values of single pollutant based on the non-carcinogenic effects of the above three groundwater exposure pathways is shown in formula (3.5.26)

$$HCVG_{iov} = \frac{RfDi \times WAF \times AHQ}{IOVER_{nc\,3}} \quad (3.5.23)$$

- $HCVG_{iov}$: Groundwater risk control values based on non-carcinogenic effects of gaseous pollutant pathways from groundwater in inhaled outdoor air;
- $RfDi$: Respiratory inhalation reference dose;
- WAF: Reference dose allocation ratio for exposure to groundwater;
- AHQ: Acceptable hazard merchant;
- $IOVER_{nc\,3}$: Groundwater exposure to gaseous pollutants from groundwater in inhaled outdoor air (non-carcinogenic effect);

$$HGCV_{iiv} = \frac{RfDi \times WAF \times AHQ}{IIVER_{nc\,2}} \quad (3.5.24)$$

- $HGCV_{iiv}$: Groundwater risk control values based on non-carcinogenic effects of gaseous pollutant pathways from groundwater in inhaled indoor air;
- $RfDi$: Respiratory inhalation reference dose;
- WAF: Reference dose allocation ratio for exposure to groundwater;
- AHQ: Acceptable hazard merchant;
- $IIVER_{nc\,2}$: Groundwater exposure to gaseous pollutants from groundwater in inhaled indoor air (non-carcinogenic effect);

$$HCVG_{cgw} = \frac{RfDo \times WAF \times AHQ}{CGWER_{nc}} \quad (3.5.25)$$

- $HCVG_{cgw}$: Groundwater risk control values based on non-carcinogenic effects of drinking groundwater pathways;
- $RfDo$: Oral intake reference measurement;
- WAF: Reference dose allocation ratio for exposure to groundwater;

- AHQ: Acceptable hazard merchant；
- $CGWER_{nc}$: Exposure to groundwater corresponding to drinking affected groundwater (non-carcinogenic effect)；

$$HCVG_n = \frac{AHQ \times WAF}{\frac{IOVER_{nc\,3} + IIVER_{nc\,2}}{RfD_i} + \frac{CGWER_{nc}}{RfD_o}} \quad (3.5.26)$$

- $HCVG_n$: Groundwater risk control values for single pollutant (NTH) based on the combined non-carcinogenic effects of the three groundwater exposure pathways；
- WAF: Reference dose allocation ratio for exposure to groundwater；
- AHQ: Acceptable hazard merchant；
- $IOVER_{nc\,3}$: Groundwater exposure to gaseous pollutants from groundwater in inhaled outdoor air (non-carcinogenic effect)；
- $IIVER_{nc\,2}$: Groundwater exposure to gaseous pollutants from groundwater in inhaled indoor air (non-carcinogenic effect)；
- $CGWER_{nc}$: 饮 Exposure to groundwater corresponding to drinking affected groundwater (non-carcinogenic effect)；
- $RfDi$: Respiratory inhalation reference dose；
- $RfDo$: Oral intake reference measurement.

5. Foundation systems

5.1 Corrosion of foundation by contaminated soil

5.1.1 Types and sources of contaminants

The pollution of foundation soil is mainly due to the leakage of some waste slag and liquid which can corrode the soil into the foundation during the production process of the factory, which causes the chemical change of foundation soil. These pollutants are mainly acid, alkali, coal tar, ash slag and so on. The main sources of pollution are acid and alkali factories, petrochemical fiber plants, gas plants, sewage treatment plants, fuel depots and some light industry factories, such as printing and dyeing, paper making, leather making and so on. In addition, there are metal smelters, steel castings, ammunition depots and other sites of the foundation soil may also be contaminated.

5.1.2 The process of foundation soil corrosion

（1） When soil is polluted, first of all, the cement salts between soil particles are corroded, the cement strength is destroyed, the salts are dissolved and lost under the action of water, the pore ratio and compressibility of soil increase, and the shear strength decreases.

（2） In the corrosion of soil particles themselves, the new substances formed after corrosion produce phase transformation crystallization in the pores of soil and expand, and gradually dissolve or split into small particles, and generate new salts containing water of crystal. Under dry conditions, the volume increases and expands, soaking shrinkage, after repeated alternating action, soil quality is damaged

（3） When the foundation soil encounters acid and alkali and other corrosive substances, it forms ion exchange with the salts in the soil, thus changing the properties of the soil.

5.1.3 Corrosion of foundation soil

There are two deformation characteristics of foundation soil after corrosion：

（1） One is to destroy the structure of foundation soil and form subsidence deformation, such as corrosion products for soluble salt. To leach or reduce soil to slime in groundwater. Foundation corrosion causes the foundation to sink, so that it is demolished and rebuilt. Because the soil grain structure is destroyed, it becomes loose and porous, so that the foundation produces uneven deformation and causes its softening device to tilt.

（2） The other damage is caused by the expansion of the foundation soil, and the products after corrosion have the property of crystal expansion, such as sodium hydroxide workshop, quicklime embedded in the foundation, etc. For example, the frame column and beam expand due to alkali corrosion of the foundation, causing the foundation to rise and crack; For example, the rack column beside the lye tank in the electrolytic workshop is also lifted due to foundation corrosion, resulting in uneven crane beam and reverse roof drainage

5.2 Evaluation of contaminated soil foundations

5.2.1 Appearance characteristics of contaminated soil

（1） After being polluted and corroded, the foundation soil often changes color and becomes soft, and its state changes from hard plastic or plastic to soft plastic, and some to flow plastic. The color of contaminated soil is different from that of normal soil, some are black, black brown, gray, some are brown red, apricot red, rust spots and so on.

（2） The soil layer in the foundation of the building becomes a honeycomb structure with scattered particles, rough surface, and even local cavitation. The building itself also appears uneven settlement.

（3） Groundwater is black or other abnormal color and has a special smell.

5.2.2 Evaluation of contaminated soil

The evaluation of contaminated soil includes the following contents：

（1） To find out the physical and mechanical properties, mineral composition and chemical composition of soil before and after pollution；
（2） Identify pollution sources, chemical components of pollutants, pollution routes, pollution history, etc.；
（3） Determine the corrosion of contaminated soil to metal and concrete；
（4） Identify the distribution of contaminated soil and classify pollution levels according to relevant standards；
（5） To find out the distribution and movement of groundwater and its relationship with pollution；
（6） The mechanical parameters of contaminated soil are put forward and the engineering characteristics of contaminated soil foundation are evaluated；

（7） Put forward suggestions on the disposal of contaminated soil。

Laboratory test of contaminated soil includes the following contents：

（1） According to the possible change of soil properties caused by soil pollution, the corresponding physical and mechanical properties test items are added；

（2） According to the interaction characteristics of soil and pollutants, chemical analysis, mineral analysis, phase analysis, and if necessary, microscopic structure identification of soil；

（3） Conduct contaminant content analysis, water corrosiveness analysis to concrete and metal；

（4） Considering the time effect of interaction between soil and pollutants, the comparative tests of contaminated and uncontaminated and different degrees of pollution are made.

5.2.3 Evaluation of contaminated soil foundations

The evaluation standard of contaminated soil foundation is that the foundation soil itself has been polluted and corroded, and the existing environment has corroded concrete and metal materials.

（1） The evaluation criteria for concrete corrosion by soil layer are as follows：

i. Evaluation criteria for crystalline corrosion：

Corrosion rank	**The content of SO_4^{2-} in hydrochloric acid leaching solution of soil (g/kg)**		
	Kind I environment	Kind II environment	Kind III environment
No corrosion	<1.0	<3.0	<5.0
Weak corrosion	1.0-3.0	3.0-5.0	5.0-10.0
Medium corrosion	3.0-5.0	5.0-10.0	10.0-15.0
High corrosion	5.0-10.0	10.0-15.0	15.0-20.0

Table 8- Evaluation criteria for crystalline corrosion

ii. Decomposition corrosion evaluation criteria:

Corrosion rank	**PH 值**		
	Kind I environment	Kind II environment	Kind III environment
No corrosion	>6.5	>6.0	>5.0
Weak	6.5-5.5	6.0-5.0	5.0-4.0

corrosion			
Medium corrosion	5.5-4.5	5.0-4.0	4.5-4.0
High corrosion	<4.5	<4.0	<4.0

Table 9- Decomposition corrosion evaluation criteria

Note: PH can be determined directly by plate electrode in soil.

iii. Evaluation criteria for composite corrosion by crystallization decomposition：

Corrosion rank	**Kind I environment**		**Kind II environment**		**Kind III environment**	
	$Mg^{2+}+NH_4^+$	$I^-+SO_4^{2-}+NO_3^-$	$Mg^{2+}+NH_4^+$	$CI^-+SO_4^{2-}+NO_3^-$	$Mg^{2+}+NH_4^+$	$CI^-+SO_4^{2-}+NO_3^-$
	[g/kg]					
No corrosion	<1.5	<3.0	<3.0	<8.0	<5.0	<15.0
Weak corrosion	1.5-2.0	3.0-5.0	3.0-3.5	8.0-10.0	5.0-5.5	15.0-20.0
Medium corrosion	2.0-2.5	5.0-10.0	3.5-4.0	10.0-15.0	5.5-6.0	20.0-30.0
High corrosion	2.5-3.0	10.0-15.0	4.0-4.5	15.0-20.0	6.0-7.0	30.0-50.0

Table 10- Evaluation criteria for composite corrosion by crystallization decomposition

Note: 1. The ion content is determined by water leaching solution of soil, and the soil and water ratio is 1：2.5；

2. *The corrosion of crystallization, decomposition and crystallization decomposition compound is only one kind of corrosion, so the evaluation conclusion is made according to the corrosion grade of this kind. If two or more of the three types have corrosion, the one with higher corrosion will be used as the comprehensive evaluation conclusion。*

5.2.4 Prevention and treatment of contaminated soil

（1） The prevention and treatment of contaminated soil shall meet the following requirements:

i. For potentially contaminated sites, when the interaction between soil and pollutants will produce harmful results, measures should be taken to prevent the intrusion of pollutants into the site, such as isolation of pollution sources and elimination of pollutants.

ii. For the contaminated site, when the strength of the contaminated soil is reduced, or there are other harmful effects on the foundation and adjacent components of the building, it should be treated separately according to the pollution level.

iii. The trend of pollution action should be considered when treating contaminated soil.

iv. After the construction or remediation of contaminated soil sites, the pollution diffusion of pollution sources and the interaction between soil and pollutants in the sites should be detected regularly. The monitoring of contaminated soil should be carried out in coordination with environmental monitoring.

（2） Prevention and treatment measures of contaminated soil

i. Soil replacement measures include removing contaminated soil, replacing uncontaminated soil, or using sand and gravel resistant to acid corrosion as backfill materials. Pile sand or gravel. However, the excavated contaminated soil should be treated in time, or find a place to store, or in-situ isolation, in short, cannot be discarded at will, so as not to cause new pollution.

ii. Pile foundation or cement mixing should be used for reinforcement to penetrate the contaminated soil layer, but corresponding anti-corrosion measures should be taken for concrete pile. The protective measures for concrete are shown in the following table:

Comprehensive evaluation of corrosion grade	**Protection grade**	**Cement**	**Water cement ratio**	**Minimum cement usage (kg/m^3)**	**C_3A (%)**	**Protective layer (mm)**
No corrosion	conventional	Portland cement; Ordinary Portland cement; Slag Portland cement; Pozzolanic Portland cement; Fly ash Portland cement	-	-	-	-
Weak corrosion	Level 1 of protection	Ordinary Portland cement; Slag Portland cement	0.65	35-350	<8	-
Medium	Level 2 of	Ordinary Portland	0.55	350-370	<8	30

corrosion	protection	cement; Slag Portland cement				
		Sulfate resistant cement			<5	
High corrosion	Level 3 of protection	Sulfate resistant cement	0.45	70-400	<5	40
Severe corrosion	Special protection	Concrete surface with asphalt or polymer resin coating film protection				

Table 11- Protective measures for concrete

iii. The surface of the metal structure is protected by isolating the coating layer from the corrosive medium. Before adding the coating, remove the oxide scale, rust, grease, miscellaneous paint and other substances on the metal surface or spray metal zinc. Coating requirements and metal have a strong bond, waterproof, heat resistance, insulation, high chemical stability, good mechanical strength and toughness. Steel and aluminum structure protection with paint: asphalt, oxidized rubber, epoxy resin and so on.

The cathodic protection of magnesium alloy or aluminum alloy as sacrificial anode and graphite as auxiliary anode for impressed current can be used for steel structures.

iv. Take preventive measures to minimize the leakage of corrosive media into the foundation, so as to minimize the corrosion of the foundation soil. If surface waste water ditches, drainage ditches and water discharge slopes are kept unblocked, measures may be taken to completely isolate the pollution sources when necessary.

v. According to the nature of the soil, appropriate measures for foundation reinforcement and prevention of re-pollution are taken.

6. Monitoring

6.1 Personnel protection and vehicle control

The purpose of contaminated site restoration is to protect human health and ecological environment. In the restoration process, no matter the volatilization of pollutants, contaminated soil dust, or contact with contaminated water may enter the human body through breathing, skin or reference, etc., so it is necessary to carry out safety protection for the construction personnel. At the same time, people and vehicles in and out will be contaminated with contaminated soil, and pollutants will spread out with people moving and vehicle transportation, so people and vehicles should be strictly controlled.

6.2 The ectopic disposal process of contaminated soil and groundwater meets the requirements

For contaminated soil requiring ectopic treatment, soil excavation, transfer, transportation and disposal should be carried out during the remediation process, which should comply with national or local laws and regulations on solid waste. If volatile pollutants are found, they should be covered during excavation and sealed during transportation in accordance with relevant laws and regulations to avoid secondary pollution caused by volatile substances. During the transportation of soil containing pollutants, the contaminated soil on the transportation lane, car body and wheels should be cleaned up to prevent the pollutants scattered outside the field. During transportation of soil containing volatile/semi-volatile organic pollutants, vehicles should be sealed to prevent contaminants from spilling out.

6.3 The treatment of "three wastes" in the disposal process

People present large-scale mining activities on the ground will change the distribution of soil pollutants, cause pollutants to a wider spread, and the potential for mining activities produce the negative impact of the health, safety, therefore, should try to take cover and other measures to control dust and the freedom of volatile pollutants emissions, protect the environment and human health from harm. In the treatment of soil and groundwater, such as leaching and other methods, may affect the natural environment, should avoid soil erosion in the site; The waste sediment and waste water generated in the process of water treatment should be treated centrally to prevent random stacking of secondary pollution. Site excavators and other equipment work and transport vehicles in and out frequently, if necessary, should carry out traffic control, to avoid the impact on local traffic; At the same time, we should try to avoid the rest time of the surrounding masses, especially in the dense area of residential areas, and reduce noise control under a certain standard.

6.4 Disposal of replacement materials

In order to ensure the repair effect, the activated carbon used to adsorb pollutants and the filling materials in the permeable reaction wall need to be replaced regularly. A large number of pollutants have been accumulated in these materials, and it is very easy to cause secondary pollution if discarded at will. Therefore, centralized disposal and replacement of such materials should be carried out in accordance with the relevant national regulations.

6.5 Disposal of enrichment medium

Some plant repair, physics and physical chemistry repair technology, enrichment effect is used to remove pollutants from the medium, such as super cumulative plants for heavy metal enrichment, aeration and electrodynamics repair technique in the concentration of pollutants in soil, etc., after processing the medium with high concentration of chemicals, in conditions allow for recycling, Otherwise, centralized treatment or unified management shall be carried out in accordance with relevant national regulations.

6.6 Regular monitoring

When using thermal desorption, burning or soil the processing techniques such as gas phase extraction, due to the temperature condition or treatment, exhaust gas or harm more pollutants, the more serious effects on the environment, for example, contaminated soil containing chlorobenzene under the condition of high temperature is easy to produce dioxins, high toxicity, enough to threaten the environment and human health. For the remediation technology of this kind of toxic gas, it is necessary to monitor the tail gas, and effectively treat it to achieve the standard discharge, so as to prevent harm to human health and ecological environment.

7. Cases Analysis

In this chapter, the guide will classify the following cases according to the types of repair technologies, which are respectively classified according to PRB technology, chemical oxidation repair technology, and chemical oxidation combined repair technology.

Case 1: Based on PRB technique

7.1The principal of PRB technique

Permeable reaction wall (PRB) technology is a popular technology for site restoration in the world. It mainly intercepts pollution plumes through active material walls so that the plumes can be precipitated, adsorbed, reduced or biodegraded. It has the advantages of good treatment effect and low investment cost, and it has been maturely applied in the United States and other countries.

This case introduces representative application cases in the United States to provide reference for the application of PRB technology in this guide.

7.2 Cases analysis

7.2.1 Case A of grain silo site restoration

(1) Location: American Midwest

(2) Main pollutants: Carbon tetrachloride, chloroform, methyl chloride, dichloromethane

(3) Method: Injection PRB

(4) Reaction medium: Mixture of zero-valent Fe and carbon

(5) Remediation Aim:

Carbon tetrachloride	<5μg/L
Chloroform	<10μg/L
Methyl chloride	<20μg/L
Dichloromethane	<5μg/L

Table 12- Remediation aim

(6) Projection start date: April 2005

(7) Long-term monitoring time: more than 5 years

(8) Running cost: \$400/m^2

(9) Site overview:

The site geology is mainly composed of loose sediments, covered with shale, the aquifer is mainly sandy clay, and the shale aquifer is about 3m above the groundwater level, northwest. The groundwater level is about 1-10m underground, the groundwater flow direction is in the southeast direction, the vertical hydraulic gradient is about 0.002-0.004, and the groundwater flow rate is in the range of 0.3-0.7 m/d.

(10) Technical description:
Select the polluted soil and groundwater of the target site to conduct small-scale experiments, and determine the proportion of reaction medium to be added in the pilot-scale experiments. In April 2005, during the actual site remediation, the reaction medium with a mass of 24 t was injected into the saturated sand-bearing layer within the 82 m width of the carbon tetrachloride pollution plume in the form of cement-containing slurry. There are 27 injection well groups set up on site with an injection depth of 6.7-13.4m and a total of 126 injection holes. The addition ratio of the reaction medium is 1% (mass ratio). Before injection, 7 soil drill holes were set up to obtain geological and analytical data around the injection area, and to determine a suitable reaction medium injection area. After injection of the reaction medium, confirm the physical layout of the reaction medium with 5 soil drill holes.

(11) Restoration effect:
In the first 4 months after the site was set up with PRB, the carbon tetrachloride removal rates monitored in the monitoring wells of 21 m and 43 m were 76% and 88%, respectively. And after 16 months of system operation, the removal rate is the highest, reaching more than 99%, and the residual carbon tetrachloride concentration is less than 5 μg/L. After two years of system operation, the removal rate fluctuated around 95%, and the system reached stability. At the beginning of carbon tetrachloride degradation, the concentration of chloroform dropped below <8.4 μg/L, which was lower than the site background value and initial concentration. In monitoring after May 2006, the concentrations of methyl chloride and dichloromethane were both below the detection limit. After 22-54 months of system operation (April 2004), the monitoring well with a concentration of 183 m, the monitored carbon tetrachloride concentration degradation rate reached 91%, and the concentration decreased from <140 μg/L to <13 μg/L, chloromethane and dichloromethane were not detected. In addition, after the repair is completed, set up long-term monitoring wells, the depth of the monitoring wells are: 21, 43, 183m, sampling every 4-8 months, a total of 5.5 years of monitoring.

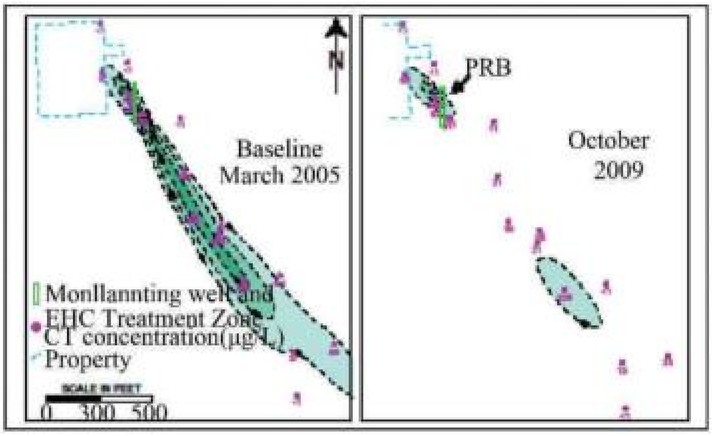


Figure 6- The distribution of pollutants on the site before and after the PRB system is activated

7.2.2 Case B of Vandenberg Air Force Base Site Restoration

(1) Location: Air Force Base, California, USA
(2) Main pollutants: Trichloroethylene, Cis-1,2-chloroethylene, Vinyl chloride
(3) Method: Deeping mixing
(4) Reaction medium: Zero-valent iron impregnated granular activated carbon (BOS100θ)

(5) Remediation Aim:
Limit the migration of contamination plumes and stop the discharge of vinyl chloride and its by-products into local streams. Contaminant concentration limits are determined based on USEPA and California Contaminant Toxicity Control Reference Values.

(6) Projection start date: September 2009
(7) Long-term monitoring time: about 1 year
(8) Running cost: \$400/m^2

(9) Site overview:
The site is covered with small to medium-grain fine sand, with organic-rich clay and bedrock below. The groundwater level is about 7.6 m underground, and the saturated aquifer is about 6 m thick. The permeability coefficient is about 37.4-48.7 m/d, and the groundwater flow rate is about 0.9 m/d.

(10) Technical description:
Due to the heavy sand and deep bedrock depth, traditional trenching techniques are not suitable. Therefore, high-pressure injection is used for the two-stage direct injection. According to

the analysis results of soil samples, the reaction medium is unevenly distributed in the subsurface, so deep stirring is used to obtain a uniform distribution of the reaction medium in the PRB treatment area.

A total of two PRBs were set up. The PRB1 area was 15 m long and 1.5 m wide (the size of the drill), and 6.6 t of reaction medium was uniformly mixed in the depth range of 8.5-21.5 m underground; the PRB2 area was 15 m long and 1.5 m wide. The mass of the reaction medium is 3.5 t, and the depth is 8.5-15 m underground. The reaction medium is mixed with guar and added as a slurry.

The laboratory test combined with the on-site pilot test was used to determine the load parameters of the PRB system and the required number of drilling rigs. The results show that when the concentration of the reaction medium is about 200kg/m3, a uniformly mixed reaction wall can be obtained. In addition, experiments have demonstrated that the system does not produce dichlorination products such as vinyl chloride.

(11) Restoration effect:
Before the PRB system was set up, the highest concentrations of pollutants in the site were: trichloroethylene 274 μg/L, cis-dichloroethylene 381 μg/L, and vinyl chloride 4 μg/L. Slow degradation of the guar used in the system, extending the treatment period by at least 2-3 months. Five months after the system was set up, the contaminants were significantly degraded and no newly produced vinyl chloride was detected.

Additional monitoring wells set up in the site are used to further evaluate the processing efficiency of the system and determine whether the PRB technology is suitable for site-wide application. During the implementation of the system, no enzymatic breaker was used in the system, considering that the guar would be degraded prematurely, and the introduction of BOS100θ into the injection line or the collapse of the fine sand.

However, the presence of guar and slow degradation introduced a prolonged reaction time in the system, where one PRB stimulated biodegradation of trichloroethylene to cis-dichloroethylene, but not the desired outcome for this project. Therefore, in future applications, enzymatic breakers are recommended.

Content ≥ 20%, moisture content less than 80%, dry fermentation has the advantages of less water consumption, can increase gas production, shorten gas production cycle, reduce biogas slurry volume, can produce clean energy and produce organic matter, etc. Nitrogen organic firming effect is better. However, the large concentration of dry fermentation materials, uneven transfer of intermediate products and heat, and system operation control, etc., large-scale production needs to be further studied.

7.3Conclusion

After 40 days of anaerobic fermentation of tea residue, the cumulative gas production was 5270ml, and the average daily gas production was 132ml. The gas production rate of TS is 658ml/g-TS; the accumulated methane amount is 1822ml, and the average daily methane production is 45.55ml. The methane production rate per unit mass of raw material is 227.7CH4-ml/g-TS. It can be seen that tea residue has good gas production potential, is a good raw material for biogas fermentation, and has good biomass energy utilization value.

Through experiments, the optimum process conditions were obtained as moisture content of 85%, temperature of 55°C, and sludge inoculation rate of 20%. In the production of biogas projects, it is recommended that the fermentation time is more than 30 days, and more than 80% of the methane gas in the total gas produced by the fermentation of tea residues can be recovered.

7.4summary

PRB is a very mature in-situ repair technology in the international market, and there are many successful cases in the treatment of heavy metals, benzene series and chlorinated solvents.

Low energy consumption, low cost, and small demand for equipment. It has high promotion value and is a reproducible green and sustainable restoration technology.

Case 2: Based on Chemical Oxidation Repair technique

7.5The principal of Chemical Oxidation Repair technique

Chemical oxidation remediation technology can quickly and effectively remove pollutants, has strong adaptability to different types of sites, is easy to detect and maintain after remediation, and has low cost, so it is widely used in the remediation of contaminated sites. Commonly used oxidants include permanganate, ozone, hydrogen peroxide and persulfate.

The main pollutants in organic polluted sites include benzene series (BTEX), petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), methyl tertiary butyl ether (MTBX), polychlorinated biphenyls (PCBs), phenols and herbicides Wait. Due to the different characteristics of different pollutants, the demand for oxidants during remediation is different, and at the same time, the site characteristics of different polluted sites have different selectivity for oxidants. Therefore, this case introduces the application design method of chemical oxidation remediation, combined with the case of chemical oxidation remediation of contaminated sites in the United States, to illustrate the application of different oxidants to the remediation of pollutants and sites with hydrogeological conditions.

7.6 Cases analysis

7.6.1 <u>Case A of Restoration of USG's legacy site (groundwater)</u>

(1) Location: La Mirada, California

(2) Main pollutants: Trichloroethylene (TCE), 1,1-Dichloroethylene (1,1-DCE)

(3) Oxidant: Potassium permanganate ($KMnO_4$)

(4) Site overview:

The aquifer sediments of the site are mainly silty sand and sandy silt, and the interlayers are clay and clayey sand. The permeability coefficient of the livestock water layer is extremely high, which is 5.48m/d. And the thickness of the aquifer is about 7.62m. The groundwater flow direction is 5.18cm/d. According to the Los Angeles Water Quality Control Society, the area of the affected aquifer is a potential source of drinking water and therefore needs to be rehabilitated.

(5) Pollution characteristics:

The pollution depth is about 24-32m, and the pollution plume range is about 5110m^2. The pilot test of this case selects a small area of pollution plumes for testing, the experimental area is about 128m^2, and the maximum pollutant concentration TCE=45μg/L, 1,1-DCE=700μg/L.

(6) Restoration design:
This is the first chemical oxidation restoration project in the Los Angeles watershed, and the restoration plan is derived from the original restoration technical guidelines approved by the Los Angeles Water Quality Control Society. The pilot test uses a single injection well to demonstrate the feasibility of $KMnO_4$ remediation. The oxidant was injected into 6 groups, each injection was 5678L, KMnO4 with a mass concentration of 5%, and the total injection volume was 34068L. According to the water quality changes measured on site, the effective treatment radius is determined to be about 10.7m. The actual site is affected by the hydraulic gradient of groundwater extraction, and the actual treatment radius is increased by about 4.6m. (Pink, Purple), used to evaluate the dispersibility and consumption of KMnO4 oxidant.

Through the small test: ① Determine the degradation amount of vinyl chloride (TCE, 1,1-DCE); ② Evaluate the secondary pollution effect of the remediation technology; ③ Provide design parameters for the site restoration project.

(7) Restoration results:
Oxidative restoration of contaminated sites with KMnO4 injection, the removal rate of TCE and 1,1-DCE can reach 86%-100% in the short term, and there is no concentration rebound phenomenon in the monitoring for 12 consecutive months after restoration. For TCE, within 70 days, the TCE concentrations detected by the 3 nearest monitoring wells (within 10.7 m) were all below the detection limit (<1.0 μg/L), and the maximum degradation amount was 280 μg/L-ND; within 70-160 days, and the detection data of the three monitoring wells added later (with a distance of 12.2-13.7m) also showed that TCE was strongly degraded, and the maximum degradation amount was 450-65 μg/L. For 1,1-DCE, the maximum degradation amount of 1,1-DCE monitored by one monitoring well is 270 μg/L~ND, and the maximum degradation amount of 1,1-DCE monitored by the other five monitoring wells is 700-19 μg/L.

7.6.2 <u>Case B of Repair of the remaining site of fuel distribution point (Soil)</u>

(1) Location: Ilion, NY
(2) Main pollutants: Polycyclic Aromatic Hydrocarbons (PAHs)

(3) Oxidant: O_3-O_2

(4) Site overview:

The site is located in northern New York. The soil composition includes local original soil (silty soil) and filling and covering soil, and the water level is 2.1~2.4m. The site is facing secondary development and utilization, but soil pollution is a big problem for grooving construction, so soil remediation is required.

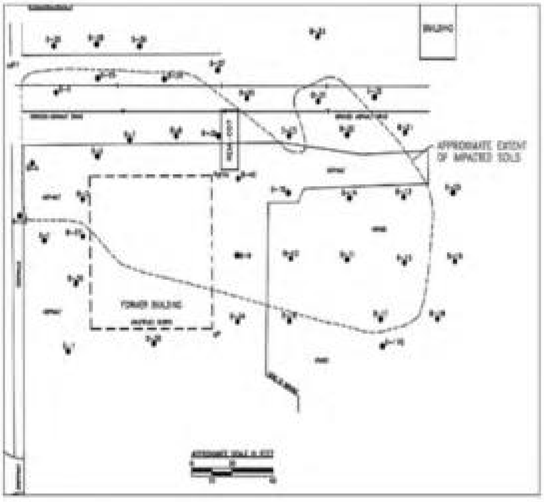


Figure 7-Schematic diagram of contaminated soil area

(5) Pollution characteristics:

The pollution mainly occurred near the oil filling abutment area, the pollution area was about 1858m2, the pollution depth ranged from 0.6 to 2.4m, and the affected earthwork volume was more than 4587m3.Main pollutants including benzene and anthracene, benzopyrene, benzene and fluoranthene and acetone in flexion, total pollution concentration range of 13500 ~ 32520700μg/L, specific see table.

PAH Compound	Content/($\mu g \cdot kg^{-1}$)		TAGM 4046 standard value/($\mu g \cdot kg^{-1}$)
	Average	Maximum	
Benzoanthracene	1410	2900	224
Benzopyrene	536	1200	61
Benzofluoranthene	1050	2300	224
Benzofluoranthene	980	2500	224
Chrysene	1077	2200	400
Total STARS PAHs	13540	32520	NA

Table 13-Table of different PAHs concentrations in the site

(6) Restoration design:

PAHs-contaminated soil is usually rehabilitated by off-site landfill or heat treatment, and the remediation time is at least 60 days. In order to ensure that the repair is completed within this time, it is theoretically necessary to configure an ozone generation system with a daily output of 45L/d to generate the O2 and O3 required for the repair.

In this case, a total of 10 injection points are set for direct injection, and a shallow gas extraction system is provided to control the system gas discharge. Set up a multi-point, continuous ozone monitoring system to monitor the surrounding oxygen concentration and control the safety of the system. After remediation, the PAHs removal rate needs to be higher than 90% to meet the requirements of the New York City TAGM4046 soil standard. Therefore, the total hydrocarbon content of the target zone needs to be reduced by about 75%.

Through the small test: ① Determine the degradation amount of vinyl chloride (TCE, 1,1-DCE); ② Evaluate the secondary pollution effect of the remediation technology; ③ Provide design parameters for the site restoration project.

(7) Restoration results:

After restoration, the soil quality of the site meets the requirements of the TAGM4046 soil standard. The effective removal rate was higher than 90% within 60 days, and the concentration of PAHs was lower than the detection limit by rapid detection and analysis of the restored soil samples.

7.7Summary

From the case of chemical oxidation remediation of organically polluted sites in the United States, it can be seen that:

(1) Chemical oxidation remediation is suitable for the remediation of various polluted sites, including lumber mills, gas stations, etc.;
(2) Rich types of remediable pollutants, including BTEX, PAHs, TCE, DCE and PCP, etc.;
(3) It can be used for single-pollutant site remediation or for multiple pollutants in line with contaminated site remediation;
(4) The repair can be done with a single oxidant or a combination of multiple oxidants.

Case 3: Based on Chemical Oxidation Combined Remediation technology (Engineering case of chemical oxidation combined remediation technology in organic polluted site of pesticide plant)

7.8Introduction

This case introduces the remediation project of polluted site of a retired agricultural pharmaceutical factory in Guangxi, China. Through the investigation of the site environment, the pollutants are determined as arsenic, chloroform, 1, 1, 2-trichloroethane, petroleum hydrocarbon and boresphosphorous. The remediation project amount is 20,900 m^3 (including 10,300 m^3 contaminated soil, Odor area soil 10600 m^3) site overall take site ectopic repair technology, single to stabilization of heavy metal pollution repair technology, the chemical oxidation of organic contaminated soil remediation technologies, heavy metals and organic compound pollution by chemical oxidation + soil stabilization repair technology, involves the smell area soil using room temperature resolution. The third party inspection institution tested the cleared foundation pit and the treated contaminated soil, and all the samples collected met the acceptance standards. The successful implementation of the project provides a reference for the similar pesticide plant contaminated site remediation project.

7.9Background

The project site is located in Hezhou, Guangxi, China, covering a total area of 48986.40m^2. It was established in 1970, and its main products are rosin, pesticide preparations (chlorinated 203, chloramidine, chlorbicide, dimethyl tetrachloride, etc.) and intermediates (phosphorus trichloride and phosphorus pentoxide), which were discontinued in 2002. In 2008, most of the factories were demolished. After demolition, the main uses were parking lots and temporary storage sites for iron ore (a few areas).

According to the local control detailed plan, the area of 5099.12m^2 is planned for roads and traffic facilities (through the middle of the site). The area of 43842.15m^2 is planned as residential land. The area of 45.13m^2 is planned as village construction land. The results of environmental investigation and risk assessment of the site from 2017 to 2018 showed that the soil in some areas of the plot was contaminated by arsenic, chloroform, 1, 1, 2-trichloroethane, petroleum hydrocarbon, and boresphosphorous, which needed remediation. The soil remediation in the site mainly consisted of 06.0m of contaminated soil, and the calculated remediation amount of contaminated soil was 10340.8m^3. From October 2018 to March 2019, the contaminated soil of the site was rehabilitated using the original site ectopic remediation technology.

7.10 Site pollution and risk profile

After site investigation, it was found that there were 6 kinds of pollutants in the soil, including heavy metal pollutant 1 (arsenic), 3 kinds of volatile organic pollutants (chloroform, ethylbenzene, 1, 1, 2-trichloroethane), organophosphorus pesticide to treat borenophosphorus, petroleum hydrocarbon, etc. According to the relevant guidelines of China, risk assessment of the above pollutants is required to determine the risk status of pollutants exceeding the standard to human health.

After risk assessment, the hazard factors of arsenic, 1, 1, 2-trichloroethane and chloroform within 0-2.5m of the site are 2.32E+02, 1.45E+00 and 1.65E-01, respectively. The carcinogenic risks of arsenic, 1, 1, 2-trichloroethane and chloroform were 4.33E-03, 8.59E-06 and 2.49E-06, respectively. All three present health risks that need to be fixed. The carcinogenic risks of arsenic and 1, 1, 2-trichloroethane in the depth range of 2.5-4.5m were 2.16E-04 and 2.41E06, respectively, and the hazard factors of arsenic, 1, 1, 2-trichloroethane and treatment of boresp were 1.93E+01, 4.11E-01 and 9.87E+01, respectively. All the three substances have health risks and need to be repaired: the hazard quotient of 4.5-6.0m treatment of borer phosphorus is 5.65E+00, which has health risks and needs to be repaired. The cancer risk of 6.0-13.0m was lower than 10-6; Hazard quotient for 1, there is no health risk.

Through risk calculation, the restoration target value of the site is obtained as shown in the following table:

Pollution factor	Arsenic	Phosphate	Petroleum hydrocarbons	Chloroform	1,1, 2-trichloroethane
Fix target value/(mg·kg^{-1})	60 (leaching 0.01mg·L^{-1})	32	826	0.3	0.6

Table 14- Restoration target value of the site

The soil in the restoration depth of the site is mainly filled with miscellaneous soil and clay. The groundwater flow direction is from north to south, and the groundwater level is about 2.4m deep

7.11 Repair technical scheme

According to the site remediation technology scheme, the contaminated soil of the site shall adopt the original site ectopic remediation technology, and the heavy metal arsenic contaminated soil shall adopt the stabilization remediation technology.1,1, 2-trichloroethane and chloroform were used to treat borer phosphorus and petroleum hydrocarbon (C_{10}-C_{40}) contaminated soil by chemical oxidation technology. Chemical oxidation + stabilization remediation technology is adopted for heavy metal and organic compound polluted soil, chemical oxidation remediation technology is adopted for organic soil and irritating odor compound polluted soil, and ectopic normal temperature resolution technology is adopted for irritating ectopic soil. The technical route of repair is shown in the figure below.

7.12 Repair effect

To dig through the acceptance of the unit after excavation and repair of soil sampling and send the third-party testing unit testing results show that the detection of 100 soil samples (including 9 parallel sample), test results are less than repair target, namely at the bottom of the pit wall and the detection means index meet the requirement of repair of the target, and 35 of ectopic repair soil testing soil samples. All the test results reached the repair target value.

7.13 Summary

In this case, the contaminated soil of the relocated pesticide plant is treated by means of ectopic stabilization and chemical oxidation, and the contaminated soil is treated by soil mixing mixer in the closed repair workshop. After sampling and analysis by a third-party testing institution, all samples meet the acceptance standards. The restoration method adopted in this project is economic and environmental protection, and has achieved good environmental benefits. The project has a short implementation period, quick effect, and good promotion and application value, which provides reference for the remediation of polluted sites in similar relocated agricultural pharmaceutical plants

Case 4: Based on Ectopic Thermal Desorption technology

7.14 Introduction

Thermal desorption technology has a good effect on the removal of polycyclic aromatic hydrocarbons, petroleum hydrocarbons and other organic pollutants. Ectopic thermal desorption technology has the significant advantages of short remediation cycle and strong universality, and is widely used in the remediation of organic contaminated sites. However, since the ectopic thermal desorption remediation project involves the cleaning and transport of contaminated soil, it is easy to volatilize organic pollutants during the construction process, resulting in secondary pollution, and adversely affecting the surrounding environment of the construction area and transportation route. Therefore, in order to ensure the restoration effect and avoid secondary pollution as much as possible, it is particularly important to supervise the whole process of ectopic thermal desorption remediation of contaminated sites.

The treatment and disposal objects of contaminated site remediation projects are mostly pollutants that may endanger human health. The remediation process is characterized by strong professionalism, complex technology and high risk, which puts forward higher requirements for the corresponding environmental supervision work. Environmental supervision has been brought into the field of remediation of contaminated sites, marking the beginning of standardization, systematization and legalization of environmental supervision of remediation projects of contaminated sites. This case study takes the ectopic heat desorption remediation project of a polluted site in Beijing, China as an example, studies the key points of its environmental supervision work combined with the actual situation, analyzes the typical significance of this case, summarizes the existing problems in the process of environmental supervision, and puts forward some suggestions.

7.14.1 <u>Site and restoration project overview</u>

The site used to be the site of auxiliary facilities of iron and steel enterprises (such as transport, granary, yard, etc.), with 30 years of production and operation history. According to the results of environmental investigation and risk assessment, 29 PAHs contaminated plots were scattered in the site, with the maximum pollution depth of 4.5m and the contaminated area of 31,000 m^2. All the 16 PAHs in soil exceeded the standard, with the exceeding rate of

0.43%34.89%, and the highest exceeding rate was benzopyrene. According to China's "Beijing Urban Master Plan (2004-2020)", the area where the site is located is planned to be an eco-friendly industrial agglomeration, and the site will be used for residential land, commercial land and public facilities in the future. According to the project implementation plan and relevant approval documents, the site was repaired by ectopic thermal desorption technology. After the contaminated soil in the site is cleared, it is transported to the thermal desorption facility by closed special transport vehicle. After screening, crushing and other pretreatment, it is sent to the rotary kiln and heated to 500℃ for 20min.After thermal desorption treatment, the contaminated soil reaches the screening value of primary reuse, and the soil after reaching the standard can be used to backfill the original site. The test results of all target pollutants in the foundation pit after the excavation of contaminated plots must meet the site control value to be qualified.

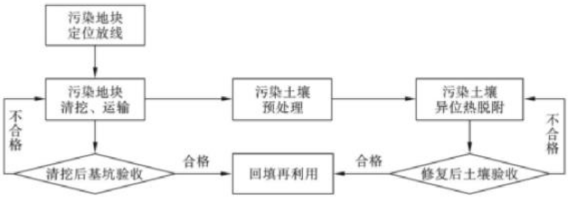


Figure 8- Site ectopic thermal desorption repair technology line

The remediation process is designed in the stages of excavation, transportation and thermal desorption treatment of contaminated soil, which is prone to produce exhaust gas, noise, wastewater and solid waste, causing adverse effects on the site and its surrounding environment. Therefore, it is necessary to carry out strict environmental supervision work, and supervise all links that may produce secondary pollution, so as to reduce the negative impact of construction on the surrounding environment as much as possible.

7.14.2 The Key Point of Engineering Environment Supervision Work

Environmental supervision of contaminated site remediation projects generally includes three stages: environmental supervision in the design stage of remediation projects, environmental supervision in the construction stage of remediation facilities and environmental supervision in the trial stage of remediation projects. In addition to the above three stages, the environmental supervision work of this project also includes the assistance work in the acceptance stage of the restoration project.

i. Key points of construction environment supervision in this project

Construction link	**Key points of environmental supervision work**
Construction preparation	Participate in the environmental supervision work disclosure meeting, clarify the environmental supervision requirements to the construction unit and the construction unit, and establish a communication mechanism. Urge the construction unit to set up necessary construction safety measures and safety signs, such as fences and project information notice boards.
Dig	Confirm the frog's position according to the restoration plan, and supervise the measurement and lay-out work. Stand by the side during excavation, check the excavation scope and depth, and supervise the implementation of secondary pollution prevention and control measures, such as watering and dust suppression, and covering with bare soil. After the excavation of the foundation pit is completed, assist in the acceptance and sampling, track the test results, inform the construction unit and the construction unit of the exceeding points, and supervise the expansion of the excavation work. Until the foundation pit sampling test is qualified.
Transport	Issue a five-part transport list to the transport vehicle carrying the contaminated soil, and ensure that the transport vehicle transports the contaminated soil to the temporary storage area designated by the remediation plan along the way. Check the number of transports and the volume of transport. During transportation, check whether there is contaminated soil or dust, and if there is any side, notify the construction unit to clean it up in time.
Temporary storage	Check the airtightness of the temporary storage area for contaminated soil and the anti-seepage situation on the ground to prevent pollutants from volatilizing into the

	air or seeping into the soil.
Thermal desorption treatment	Check whether the thermal desorption and exhaust gas treatment equipment meets the requirements of the restoration plan, supervise the treatment process, urge the construction unit to sample and test the treated soil in time, and conduct random inspections on the soil that has passed the test. Soil batches are reprocessed until they pass the inspection.
The in-situ backfill	Supervise and urge the construction unit to backfill the remediation soil that has passed the acceptance inspection on the original site in time, and check the secondary pollution prevention measures during the backfilling process, such as watering and dust suppression and airtight transportation. Check whether the backfill soil meets the relevant requirements of the remediation plan.

Table 15- Key points of construction environment supervision

ii. <u>Key points of secondary pollution prevention and control in this project</u>

Compared with general construction projects, the construction object of contaminated site remediation project is contaminated soil, and the site and surrounding environment are easily polluted during construction. Therefore, the prevention and control of secondary pollution of waste gas, wastewater, solid waste and noise during construction period is the top priority of environmental supervision work.

This project aims at the main points of environmental supervision for the prevention and control of secondary pollution.

Construction link	**Environmental Impact**	**Sources of pollution**	**Key points of environmental supervision work**
Excavation	Atmospheric environmental influence	During excavation, pollutants such as dust, heavy metals and VOCs/SVOCs will be volatilized. The operation of excavators, forklifts and transport vehicles will	Check whether the excavation surface is reduced as much as possible during construction, whether water is sprinkled to suppress dust, whether

		generate exhaust gas. The temporary stacking of topsoil will generate dust	there is a pungent odor, and whether the bare soil is covered in time
	Water environmental impact	Rainwater leaching during the accumulation of contaminated soil, water in the pit after cleaning and digging contaminated soil, and domestic sewage of workers	Check whether the accumulation of contaminated soil is avoided as far as possible, whether there are drainage ditches in the foundation pit, and whether domestic sewage is uniformly discharged
	Soil environmental impact	Infiltration of contaminated soil and waste through rainwater leaching during storage	Check whether the accumulation of contaminated soil is avoided as far as possible, and if so, whether there are anti-seepage measures
	Solid waste product	Dirty oil and waste oil, scrapped general facilities, equipment, tools and appliances, general household and kitchen waste	Verify whether solid waste will be collected and processed uniformly
	Noise	Noise is generated by the operation of excavators, forklifts, transport vehicles and so on	Check whether the machinery and vehicles are in good condition, whether the scope of operation is strictly controlled, whether night construction is avoided, and whether other noise reduction measures are taken
Transport	Atmospheric environmental influence	Earth transport produces dust, vehicle transport exhaust emissions	Whether the vehicle is airtight transport, whether it is overloaded, whether the transport road is timely sprinkling water and dust suppression
	Water	The contaminated soil is	Check whether there is

	environmental impact	washed by rain during transportation, and waste water is generated by cleaning facilities, equipment, tools and appliances	any residue in the transportation process, if there is, whether to take immediate cleaning measures, whether to collect and treat the waste water of machinery and equipment
	Soil environmental impact	Dust is generated during transport of contaminated soil	Whether to clean the wheels and body of the contaminated soil after loading, whether the transport wheel is closed, whether it is full and overloaded, whether it is slow down
	Noise	Noise is produced when vehicles are transported	Whether to avoid environmentally sensitive areas during transportation, whether to reduce whistle as much as possible, whether to slow down slowly
Thermal desorption treatment	Atmospheric environmental influence	Heat desorption exhaust gas, contaminated soil temporary accumulation of dust	Check whether the exhaust gas treatment device of the thermal desorption equipment is running well, whether the activated carbon is replaced in time, and whether the temporary storage area of contaminated soil is closed
	Water environmental impact	Thermal desorption of cooling water, acid - containing wastewater	Whether unified collection and treatment after standard discharge
	Soil environmental impact	During the temporary storage of contaminated soil, rainwater leaches and chemicals used in pollution control leak and spill	Whether there are anti-seepage measures in the temporary storage area of contaminated soil

	Solid waste product	Dust collected by thermal desorption process, activated carbon replaced by tail gas treatment device, soil or waste after treatment	Whether to collect data and send it to qualified units for processing
	Noise	Mechanical noise during construction	Whether to choose low noise equipment as far as possible, whether to take effective noise reduction measures
The in-situ backfill	Atmospheric environmental influence	Dust, exhaust gas emitted during operation of earthmoving machines, forklifts, vehicles, etc.	Whether water is sprinkled to suppress dust, whether bare soil is covered in time, and whether it is compacted in time after backfilling
	Water environmental impact	Facilities, equipment, tools and appliances to clean and discharge wastewater, sewage of workers	Whether the waste water is uniformly collected, treated and discharged to the standard
	Solid waste product	Dirty oil and waste oil, scrapped general facilities, equipment, tools and appliances, general household and kitchen waste	Verify whether solid waste will be collected and processed uniformly
	Noise	Noise is generated by the operation of earth-piling machines and transport vehicles	Check whether the machinery and vehicles are in good condition, whether the scope of operation is strictly controlled, whether night construction is avoided, and whether other noise reduction measures are taken

Table 16- Key points of secondary pollution prevention and control

iii. Carry out environmental monitoring during construction

Construction link	**Monitoring object**	**Monitoring location**	**Monitoring method**	**Monitoring frequency**
Excavation	On-site VOCs/SVOCs	excavation site	handheld PID	2 times a day
	Environmental air	According to the restoration plan, set up	Atmospheric comprehensive	once every 2 weeks, 1

		monitoring points at the environmental sensitive points around the site and the site boundary	sampling instrument	day each time
	Field boundary noise	According to the restoration plan, monitoring points are set up at the environmental sensitive points around the site and the site boundary	Integral average sound level meter	2 times a day
Thermal desorption treatment	On-site VOCs/SVOCs	excavation site	handheld PID	2 times a day
	Thermal desorption tail gas	/	Flue gas online monitoring system	Check and summarize automatic monitoring data every day
	Environmental air	According to the restoration plan, set up monitoring points at the environmental sensitive points around the site and the site boundary	Atmospheric comprehensive sampling instrument	once every 2 weeks, 1 day each time
	Field boundary noise	According to the restoration plan, set up monitoring points at the environmental sensitive points around the site and the site boundary	Integral average sound level meter	2 times a day

Table 17- Environmental monitoring during construction

iv. Record daily work items and prepare reports

After the restoration project is started, the environmental supervisor will record the daily work, including: environmental supervision log, site inspection and side station records, supervision meeting records and monitoring records, etc. a way.

When the implementation of the restoration project does not conform to the design, the environmental protection measures are not implemented in place or other major environmental protection problems, the environmental supervisor will timely issue a general contact sheet, a rectification notice or a stop/resumption instruction sheet according to the severity of the problem, and feedback the problem to the construction unit shall urge the construction unit to deal with it in a timely manner.

When the restoration project reaches a certain stage, the environmental supervisor will compile summary materials according to the daily records of the on-site work, including periodic reports of environmental supervision (monthly, quarterly, and annual reports), stage reports and summary reports, as the technology for the completion acceptance and effect evaluation of the restoration project. one of the materials.

7.14.3 The main points of environmental supervision in the project acceptance stage

The environmental supervision work in the project acceptance stage mainly focuses on two aspects: First, before carrying out the project effect evaluation, the environmental supervision shall check the integrity and accuracy of the construction process data submitted by the construction unit, such as errors in the engineering quantity or data that appear inconsistent with the actual situation. If the construction does not conform to the content, find out the reasons in time, and urge the construction unit to revise and improve. The second is to assist the effect evaluation unit in collecting soil samples from foundation pits and soil samples after thermal desorption, tracking the test results of the samples, and urging the construction unit to take timely measures in case of unqualified conditions until the sample test results Meet the relevant requirements in the repair plan. At the same time, to assist in the performance evaluation stage
other related work.

7.15 Typical significance of this case

7.15.1 Restoration technology representative

Ectopic thermal desorption is a relatively mature soil remediation technology, which has been widely used in the remediation of organically polluted sites at home and abroad. my country first introduced ectopic thermal desorption equipment in 2009. Since then, ectopic thermal desorption remediation technology has developed rapidly in China. As of 2017, 23 ectopic thermal desorption remediation projects for contaminated sites have been carried out. The obvious advantages of short construction period and high remediation efficiency gradually occupy a larger proportion in soil remediation at this stage. Ensuring the remediation effect of ectopic thermal desorption technology is of great significance for the remediation of organically polluted soil. Through case analysis, this study clarifies the matters that should be paid attention to in the actual work of environmental supervision of ex-situ thermal desorption remediation projects. It has certain implications for carrying out environmental supervision work of similar projects and strengthening environmental supervision of ex-situ thermal desorption remediation projects. Guiding significance.

7.15.2 Participation process comprehensive

The focus of environmental supervision is on the control of the restoration project process. Only by effectively supervising the whole process of the project and ensuring the construction quality and secondary pollution prevention measures are in place, can the final restoration effect be guaranteed. The environmental supervision work of this case covers the whole process of the contaminated soil ex-situ thermal desorption remediation project, that is, from the review of the documents before construction to the in-situ backfilling after the remediation of the contaminated soil, the work content is comprehensive, and the work flow is comprehensive. It has good cohesion and basically covers the key links of environmental supervision of such projects, and can provide a good reference and reference for similar projects.

7.15.3 Problem prevalence

The main problems in the environmental supervision work of this project are as follows: First, the status of environmental supervision is not clear, the scope of work is ambiguous, and in actual work, it is easy to have problems such as responsibilities confusion or prevarication with the project supervision, resulting in poor work. The second is the lack of professional environmental supervision personnel. Environmental supervision personnel should have both project management and environmental protection related professional knowledge and skills. The lack of any one aspect may cause deviations in the restoration project and have a negative impact on the restoration effect. The third is the lack of coordination in the organization of the restoration project. The restoration project is generally participated by the construction unit, the construction unit, the project supervision unit, and the acceptance unit. In actual work, due to the lack of an effective

coordination mechanism, the construction is blocked or communication faults, thus reducing work efficiency.
Through case analysis, sorting out problems and exploring solutions, it is necessary to improve the polluted site.The environmental supervision work of ectopic thermal desorption remediation has certain universality.

7.15.4 Suggestion

According to this case study, for the current environmental supervision work existing problems, the following suggestions are made.

(1) An authoritative environmental supervision work guide was issued. At present, there is a lack of relatively uniform standards for environmental supervision of polluted sites, which leads to problems such as unclear scope of work in actual work. Therefore, it is urgent to establish a set of scientific and reasonable standards to guide practice according to the actual situation; at the same time, it is also necessary to combine with local environmental policies to maximize local conditions.

(2) Optimize the working mode of environmental supervision. During the project preparation period, do a good job in the construction of the organizational system, refine the work content, clarify the responsibilities of all parties, and establish a good communication and coordination mechanism to ensure the integrity of the process and the effectiveness of the results of the remediation of contaminated sites. Fully cooperate with the project supervisor, temporarily set up a common leading department during the construction period, and carry out work under the unified leadership, with clear rights and responsibilities, smooth communication, and comprehensive guarantee of the quality of the restoration project.

(3) Set up a team of environmental supervision talents. Environmental supervisors need to have a more comprehensive understanding of relevant environmental protection laws and regulations, master the necessary environmental protection knowledge, and classify and summarize the characteristics of environmental pollution and ecological protection in engineering construction projects in a targeted manner. Analyze the environmental impact of construction, the implementation effect of environmental protection measures and the results of environmental monitoring. At the same time, it is necessary to be familiar with the project construction process and its characteristics, and to prevent and control possible environmental problems as comprehensively as possible.

Case 5: Mixed pollutants (heavy metal pollution and organic pollution)

7.15.5Target site topography and landforms

The survey site is a landfill in Ningbo, which is located in the southwest suburb of Ningbo, only about 10km away from the city center. The geomorphological unit of the site is mainly a coastal silt plain. It was originally a curved channel in the lower reaches of the Feng Hua River. It was straightened by cutting and bending. After the dam was built to block the water, the Feng Hua River was diverted and the abandoned channel space was used as a landfill site. The original elevation of the site is -10.63-3.04m, and the current ground elevation is 3.16-15.38m. The site is backfilled with 1.40-25.30m thick fill (including gravel fill, cohesive soil fill and domestic garbage mixed fill).

7.15.6Site contamination

Site soil pollution is mainly composed of two parts: heavy metal pollution and organic matter pollution. Among them, soil heavy metal pollution is the main problem in soil pollution. According to the on-site investigation, a total of 25 points found that the soil exceeded the standard, as shown in the table18. The soil excess factors mainly involve arsenic, nickel, copper, lead, mercury, beryllium, benzopyrene, 1,2,3-trichloropropane, etc., see the table19. The main factors of no screening value of the project are 1,1-dichloropropene, cis-1,3-dichloropropene, trans-1,3-dichloropropene, 4-isopropyltoluene, etc. It can be seen from the table18 that the factors of soil exceeding the standard or no screening value in this site mainly involve arsenic, benzopyrene and 1,2,3-trichloropropane among the above factors.

N°	Exceeded point	Sampling depth/m	Contamination thickness/m	Contamination type	Measurements /(mg/kg)	Standard /(mg/kg)
1	A4-1	3.0-3.4	<2	Benzopyrene	0.48	0.2
2	B3-3	8.5-8.9	<2	Benzopyrene	0.38	0.2
3	B4-3	8.6-9.0	<2	Benzopyrene	0.20	0.2
4	B6-3	7.0-7.4	<2	Benzopyrene	0.47	0.2
5	C1-3	10.0-10.4	<2	Arsenic	21.30	20
6	C2-1	6.0-6.4	<2	Arsenic	21.90	20
7	C5-2	14.0-14.4	2-4	Benzopyrene	0.29	0.2
8	C5-3	16.0-16.4	2-4	Arsenic	37.30	20
9	C7-1	3.0-3.4	<2	Benzopyrene	0.35	0.2
10	D8-4	10.1-10.5	<2	Benzopyrene	0.64	0.2
11	E7-1	20.1-20.5	<2	Benzopyrene	0.22	0.2
12	e7-1	13.5-14.0	<2	Benzopyrene	6.14	0.2
13	E9-2	5.0-5.4	<2	Benzopyrene	1.78	0.2
14	e9-6	17.5-18.0	<2	Arsenic	20.70	20

15	F8-1	20.6-21.0	<2	Benzopyrene	0.49	0.2
16	f8-4	14.5-15.0	<2	Benzopyrene	0.20	0.2
17	F9-3	12.0-12.4	<2	Benzopyrene	0.51	0.2
18	F10-1	4.5-4.9	<2	Benzopyrene	0.34	0.2
19	g1-4	10.5-11.0	<2	Arsenic	20.90	20
20	G2-1	9.0-9.4	<2	1,2,3-Trichloropropane	0.36	0.05
21	G4-4	8.6-9.0	<2	Benzopyrene	0.31	0.2
22	G5-2	5.0-5.4	<2	Benzopyrene	0.24	0.2
23	G7-4	13.1-13.5	<2	Benzopyrene	0.30	0.2
24	G11-3	10.0-10.4	<2	Benzopyrene	0.63	0.2
25	H5-3	7.0-7.4	<2	Benzopyrene	0.22	0.2

Table 18-Excessive soil conditions of the site

The depth of heavy metal pollution is about 14 meters underground, and the depth of organic pollution is about 12 meters underground. Therefore, there are 25 monitoring sites where the carcinogenic risk of contaminated soil exceeds the acceptable level. The main pollutants are benzopyrene, 1,2,3-trichloropropane and arsenic. To sum up, it can be seen that the soil pollution is serious and harmful to human body.

Nº	Contamination	Filter value
1	arsenic	20
2	nickel	150
3	copper	2000
4	lead	400
5	Hg	8
6	beryllium	15
7	Benzopyrene	0.55
8	1,2,3-Trichloropropane	0.05

Table 19- Some Soil Exceeding Standard Factor Projects [mg/kg]

7.15.7 Distribution and characteristics of soil pollution

According to the field investigation, the soil pollution distribution zones are summarized as shown in the figure below, and the site is divided into A, B, C, and D zones according to the scope of soil pollution. They are unpolluted area, heavy metal arsenic pollution, benzopyrene pollution area and 1,2,3-trichloropropane pollution area. It can be seen from the figure below that the heavy metal arsenic pollution area and the benzopyrene pollution area have overlapping areas, and the overlapping area is about 3.2. Moreover, the thickness of the contaminated soil at the site is mostly less than 2 meters. The distribution area and soil volume of contaminated soil are shown in Table 20.

Figure 9-Soil pollution distribution zone

Soil Area Code	Soil Contamination	Soil Area/10^4 m^2	Contaminated Earthwork/10^4 m^3
A	Unpolluted	7.6	0
B	heavy metal arsenic	13.8	12.5
C	Benzopyrene	16.0	24.4
D	1,2,3-trichloropropane	1.2	1.9
Sum		35.4	HMC:12.5
		3.2(overlapping not included)	OC:26.3

Table 20-Site soil pollution distribution area and earthwork volume

Based on the above survey results, the characteristics of the landfill site in Ningbo can be summarized:

(1) Various types of pollution are serious, showing a variety of complex pollution, with obvious differences between regions;
(2) Organic pollution is dominated by volatile pollutant benzene, and some overlap with heavy metal pollution;
(3) The pollution depth is not large, the pollution area is consistent with the factory boundary, and it is distributed in blocks;
(4) The soil clay content is high and the geological conditions are complex.

7.15.8 Process flow and benefit analysis of site soil remediation treatment plan

(1) Arsenic-contaminated soil remediation and treatment process

Taking the solidification/stabilization technology to remediate the arsenic-contaminated soil as the object, its technological process is expounded. Mainly divided into soil pretreatment, soil stirring stabilization, soil stabilization acceptance.

Soil pretreatment includes soil excavation, transportation, coarse screening, and crushing. The soil excavated by the excavator is directly grabbed to the mud truck, and then transported by the mud truck to the treatment plant for temporary storage. The temporarily stored soil is loaded by the grab machine to the rotary drum screen for coarse screening. Coarse chunks of soil are transferred to the crushing equipment, and stones that cannot be crushed will be output. The fine particles are conveyed by the belt to the twin-shaft agitator. Stabilization of soil stirring means adding a certain amount of water and chemicals to the double-shaft agitator, and after stirring for a long enough time, the belt is output to the clean soil temporary storage area, and the temporary storage area is covered and maintained. Soil stabilization acceptance is to randomly check the stabilized products of the soil temporarily stored. After testing, if the leaching concentration of heavy metals is lower than the limit of groundwater class III water quality index, it is qualified. The qualified soil will be used as roadbed material for roadbed construction. If it is not qualified, it will be blended according to the content level to screen the contaminated soil for re-stabilization.

(2) Organic matter contaminated soil remediation process

After excavation of contaminated soil with organic pollutants (mainly benzopyrene and 1,2,3-trichloropropane), after crushing and screening, the sorted polluted soil larger than 5 cm is re-crushed, and the contaminated soil smaller than 5 cm enters the temporary storage area is temporarily stored, where it is mixed with the treated soil, and the moisture content is adjusted to be less than 25% before entering the alloy rotary dryer. The treated soil is cooled by a humidifier and then backfilled or mixed with contaminated soil as a soil moisture conditioner. The organic waste gas produced by the rotary dryer is converted into carbon dioxide, water and hydrogen chloride through the incinerator after passing through the cyclone dust collector. Then pass through the cooling tower, neutralization reactor and bag filter in sequence, and finally discharge up to the standard.

(3) Site Soil Remediation Benefit Assessment

Through the risk assessment method, the results of soil remediation are compared with the standards. It can be considered that the soil remediation system designed according to this design can make heavy metal pollution (mainly arsenic) and organic pollution (mainly benzopyrene and 1, 2, 3-trichloropropane) problem has been solved, in which the arsenic pollution is reduced to below 20mg/kg, and the corresponding restoration values of benzopyrene and 1,2,3-trichloropropane pollution can be reduced to 0.2mg/kg and 0.05, respectively mg/kg. After the restoration plan was implemented, multiple monitoring points were tested and evaluated. The estimated test results of the exceeding-standard items are shown in Table 21, and 10 points were selected as the evaluation objects. Comparing the restoration targets, it can be seen that the restoration results meet the standards.

The benefit of contaminated soil remediation consists of two parts: direct benefit and indirect benefit. The site after soil remediation can be used as residential land and commercial land. Since the land is located in the urban area, the economic benefits are considerable. At the same time, after the project is completed, 3×10^6 tons domestic garbage and polluted soil, and 1.5×10^6 tons construction waste will be treated, which can completely solve the threat of the polluted soil to the water quality of the local river, and play a certain role in protecting the water source in the lower reaches of the river and the groundwater around the site. The ecological environment around the destroyed piles can be gradually restored. The soil remediation benefits of this project are significant.

Points	Arsenic	Benzopyrene	1, 2, 3-trichloropropane
1	17.7	0.16	0.04
2	18.5	0.18	0.05
3	18.3	0.17	0.04
4	17.1	0.16	0.04
5	19.3	0.19	0.04
6	19.3	0.20	0.05
7	19.2	0.20	0.04
8	16.5	0.16	0.03
9	18.6	0.17	0.04
10	18.4	0.16	0.04

Table 21-Evaluation of test results after treatment of major pollutants [mg/kg]

7.15.9 Conclusion

Taking the soil remediation of a landfill in Ningbo as an example, this study starts from the actual situation and combines the pollution characteristics of the site soil. According to the requirements, the corresponding remediation indicators and remediation plans are proposed, and the specific processes and methods are discussed. On this basis, the technological process of heavy metal pollution and organic pollution soil is given, and the potential economic benefits are analyzed, which provides theoretical and practical support for solving the soil pollution problem of old landfills, and has important use value.

The innovations of this study are:

(1) In the formulation of the soil remediation plan, the research object is the landfill. This study gives a detailed plan of soil remediation for this type of site, which has reference value for soil remediation work on the same type of site.

(2) In the process of soil remediation, heavy metals and organic pollutants are used for dual treatment, different solutions are adopted for different pollutants, and a horizontal comparison between methods is carried out, and a set of effective and resource-saving remediation solutions are obtained.