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Article 8. Management of contaminated site

------A case study in 10-12 Beaumont Street in Auckland city

Author: Liu Huan (1983-) Master of Science (First Class Honours, 2009), The University of Auckland
Advisor: laurence, School of Environment, Faculty of Science, The University of Auckland

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Abstract

Conceptual site model has been firstly established for the potentially contaminated site in the 10-12 Beaumont Street in Auckland city. The geological and hydrogeology characteristics, potential contaminants, potential contaminant migration pathways, and risk to environmental receptors have been integrated into this model. The potential contaminants that have been identified include heavy metals (e.g. lead, mercury, and arsenic), acids and alkalis, as well as petroleum hydrocarbons. The groundwater pathway, direct contact in residential garden, and stormwater drainage are the ptential migration pathways of contaminants. A number of remedial methods and technologies have been identified for this contaminated site. The assessment of these alternatives is mainly based on the technology feasibility and economic cost. Excavation of contaminated soil, soil vapor extraction, chemical fixation, *in situ* soil flushing, solvent/soil washing, encapsulation, landfarming, incineration, bioremediation and activated carbon adsorption are evaluated and considered to be applicable for the contaminated soil remediation. For the contaminated groundwater, excavation is usually the initial step. Air stripping and activated carbon adsorption have been identified as the recommended technologies in this case study.

Key words: contaminated site, Conceptual site model, groundwater pathway, contaminated soil remediation

论文题目：污染场地的风险评估和修复
----- 以奥克兰市波蒙特街10-12号为案例分析（英文）

摘要：此课题通过建立概念模型阐述了地下水和土壤污染源和迁移机理。污染场地位于奥克兰市波蒙特街10-12号。该模型反映了地质和水文特征、潜在的污染物、污染物的迁移途径和环境风险敏感目标因素之间的联系。已确定的主要污染物包括重金属（如铅，汞，砷）、酸和碱、以及石油碳氢化合物。污染物危害途径包括地下水的迁移途径、住宅花园与人体的直接接触、雨水排水等。污染场地的修复方法和技术在本文做了系统性总结和可行性对比。这些修复替代方案的评价指标主要是基于技术可行性和经济合理性。此课题探讨的污染场地修复技术主要包括土壤的挖掘、土壤气相抽取、化学固定、原位土壤生物通风、土壤化学溶剂清洗、安全填埋、土地施用法、热处理、生物修复技术和活性炭吸附法。其中生物通风和活性炭吸附被确定为此污染场地修复的推荐方法。

关键词：污染场地，概念模型，地下水污染途径，污染土壤的修复

1. Introduction

Industries play an essential role in modern society, which inevitably generate waste materials released into land. Consequently, the risk of contaminated sites has been significantly increased by industrialization. The concern on the public health and environmental impacts leads the risk assessment and remediation of contaminated site to be increasingly significant. Generally, any contaminants that are released into the environment will undergo complex processes, such as inter-media transfers, degradation, and biological uptake. The intensive investigations are required for the identification of contaminated site problems. Then the appropriate and cost-effective remedial options should be identified and well implemented for this site.

The objectives of this project are to assess the potential contaminants, potential migration pathways, and risk to environmental receptors on the basis of conceptual site model. Then the alternative remedial methods and technologies for contaminated soil and groundwater will be identified and evaluated, mainly according to their effectiveness, implementation feasibility, and economic cost.

2. Conceptual site model

2.1. Plan and methodology

This model is going to design a system diagram in three dimensions (Figure 1 below), integrating the site layout, surrounding land use, geology and hydrogeology characteristics, likely contaminant sources and releasing mechanisms, potential migration and exposure pathways, potential receptors, and their relationships. The past activities that are likely to cause land contamination will be identified according to the historical records from Auckland City Council and the 1940's plan from Auckland Gas Company Ltd. The site geology and hydrogeology characteristics were tested in November 2000 by TONKIN & TAYLOR Environmental & Engineering Consultants, using borehole, testpit, and sediment sampling in this area.

2.2. Location and layout

The contaminated site is located in the 10-12 Beaumont Street in Auckland city. This site has been developed into a residential apartment. To the east of contaminated site, the Victoria Park is located on the other side of Beaumont Street, which used to be a landfill.

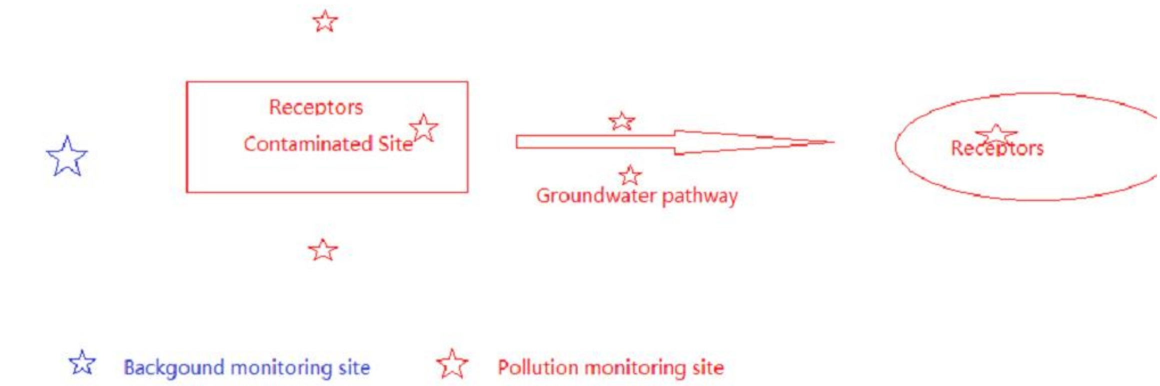
2.3. Geology and hydrogeology characteristics

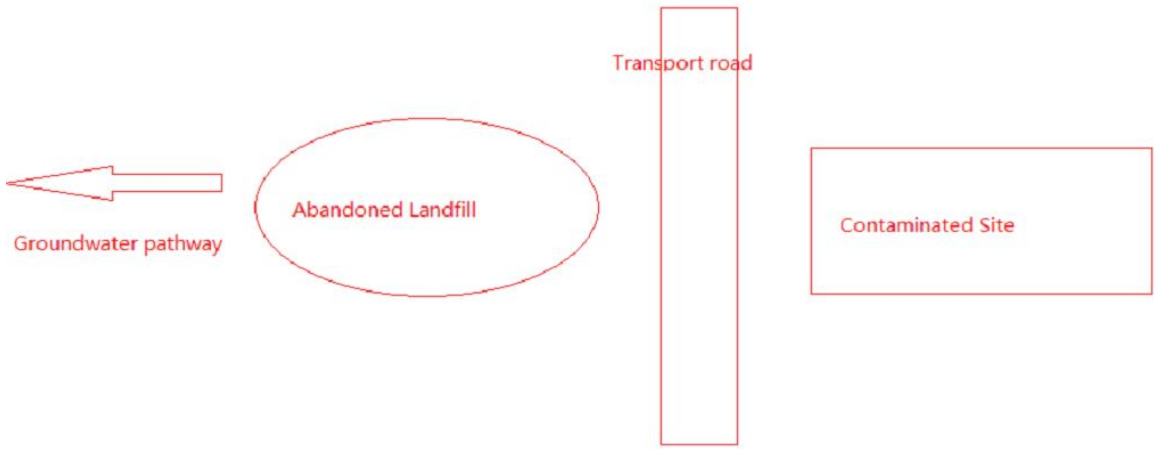
The geology and hydrogeology characteristics in the contaminated site are essential for the identification and assessment of potential contaminants and their pathways. Usually, the geological characteristics for contaminated site assessment include the types of geology materials, structural geology features, depositional environment, and geomorphology. The geological composition information may be gained from the existing documents from the local geology state office (Martin, 2007; Murray, 2008). However, the site-specific sediment and testpit sampling are also essential. Especially, the variations in strata surfaces may be the important indicators for land contamination (Murray, 2008).

Usually, the essential hydrogeology characteristics should include aquifer factors, hydrologic budget, and groundwater flow. These hydrogeology characteristics will influence the hydrodynamic dispersion of soluble contaminants, including the direction of soluble contaminant migration, and the duration and amount that contaminated groundwater will reach receptors. In the hydrodynamic dispersion process, the contaminants will be distributed over a larger volume in the aquifer and will be diluted (Laurence, 2008). Each of these hydrogeology characteristics will be discussed below.

Groundwater flow

The groundwater flow factors usually include hydrology gradient (indicating the changes in water elevation over changes in flow distance), flow velocity, and other boundary conditions. The high flow velocity will stimulate the hydrodynamic dispersion of contaminants. Site-specific borehole monitoring program is required for this assessment. However, to ensure the validity of groundwater data, the hydrogeology sampling should be carried out on a basis of datum, and should be finished within a short period of time, which eliminates the inaccurate factors caused by the tidal and rainfall effect (Martin, 2007; Murray, 2008). According to the groundwater monitoring data from T&T, the direction of groundwater flow is from the west of contaminated site to the east (Victoria Park).





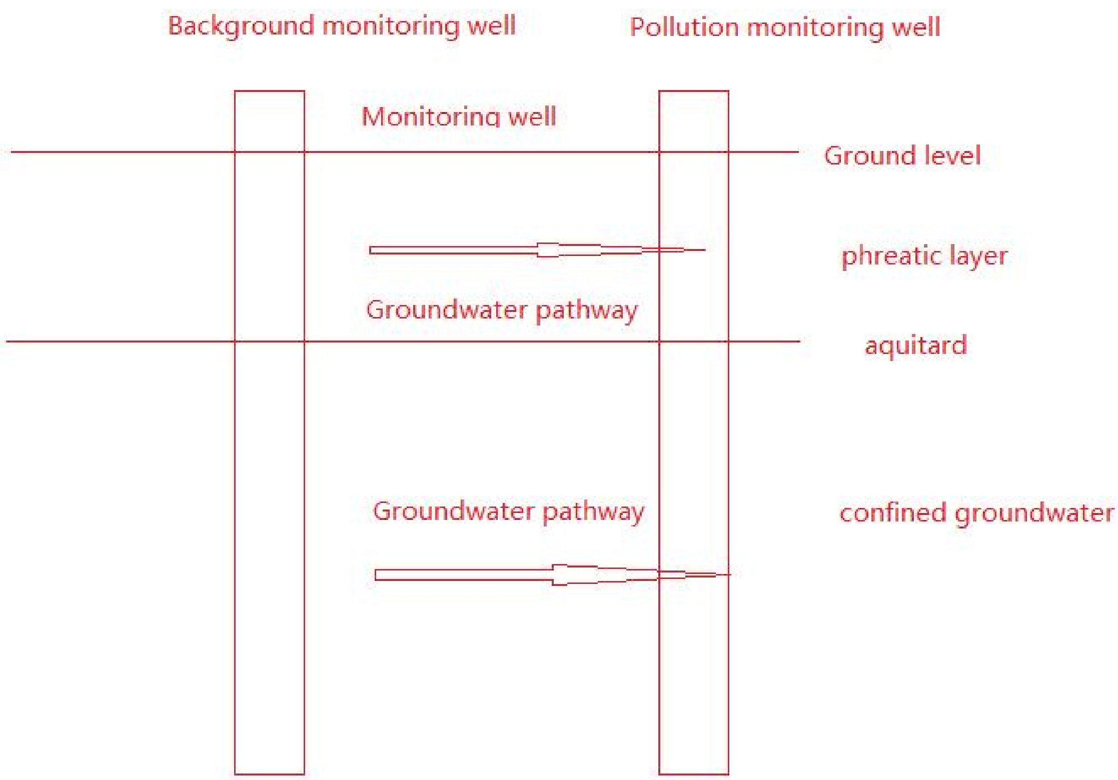


Figure1. Conceptual Model of Contaminated Site.

Aquifer

The assessment of aquifer features should include aquifer thickness, confined or unconfined factors, geological materials and structure, hydraulic conductivity, and moisture storage capacity (Martin, 2007; Murray, 2008). Particularly, hydraulic conductivity indicates the intrinsic permeability of aquifer materials, which measures the quantity of water that will be transmitted into 1 unit cross sectional area under 1 hydraulic gradient in a unit time (Darcy's Law). Hydraulic conductivity is mainly influenced by grain size, grading, fracturing, and rock type (Laurence, 2008). Usually, the clay and silt types have low hydraulic conductivity (ranging from 10^{-8} to 1 metres /day), while the gravel and coarse sand have relatively high hydraulic conductivity (ranging from 20 to 1000 metres/day) (Robert, 2006).

Hydrology budget

The hydrologic budget can be determined by the balance between the recharge rate and discharge rate. The hydrologic recharge mainly relies on precipitation, which can be estimated according to the local meteorology records. On the other hand, the parameters of hydrologic discharge should include evaporation, stream outflow, and groundwater pumping, which requires site-specific test (Martin, 2007; Murray, 2008).

2.4. Potential contaminants

According to the previous records from Auckland City Council and the 1940's plan from Auckland Gas Company Ltd, the past activities which are likely to cause land contamination should include: the discharge of radiator cleaning and draining water into the stormwater drainage system by the Radiator Rebuilds Company; the potential leakage from tar tank, tar pipelines, and tar plant store & sales (in 1940s); the potential leachate released from the landfill under Victoria Park; and the inappropriate installation of dangerous good.

Therefore, the likely contaminants in this site can be predicted according to these activities. The radiator drainage may lead to chemical contamination, including: the acids and alkalis, heavy metals, and waste oils. These contaminated radiator drainage can be transported into streams (such as river) through stormwater drainage system, and may also be released into aquifers along drainage system. The potential hazardous substances that were released from the petroleum and gas pipelines, tar tank, and tar plant store & sales should include Benzo-a-pyrene (BaP), hydrocarbons, oily waste, lead, and phenols (Kofi, 2005). These contaminants were initially released into unsaturated soil, and then they can be percolated into groundwater. However, the landfill leachate impacts on the proposed site (10-12 Beaumont Street) will be strongly determined by the direction of groundwater flow under this area. In this case, the leachate may not be able to be transmitted to the proposed site (10-12 Beaumont Street), because the direction of groundwater flow is away from the contaminated site.

Toxicity

The toxicity of contaminants indicates the degree of adverse effect on the human health and environment, which can be judged by comparing the related environmental standards, e.g. acceptable daily intake (ADI) from World Health Organization (WHO). In this case, the potentially toxic substances are heavy metals (e.g. mercury, arsenic, and lead), acid and alkalis solutions, and petroleum hydrocarbons, which are relatively persistent in aquifer and bio-accumulative (Ministry for the Environment, 2004).

Extent/Quantity

The extent or quantity of hazardous substances is to measure the proportion of affected site or the amount of potential contaminants on the site. Only the value at the time of assessment will be considered, regardless of historical contaminant data. Usually, this parameter will be measured independently of the toxicity. However, the assessment of contamination sources will combine the toxicity, e.g. the risk of a small quantity of highly toxic hazards is equivalent to a large quantity of hazards with lower toxicity. The extent/quantity of hazardous substances is also closely related to the contaminant accessibility to receptors, which should also be integrated into the risk assessment, e.g. a small amount of lead that are easily accessible to children in the residential garden should be equivalent to a high value of extent / quantity (Ministry for the Environment, 2004; U.S Environmental Protection Agency, 2007).

Mobility

Mobility of hazardous substances indicates the migration ability of contaminant through potential pathways. Usually, the contaminants with high mobility are more likely to access receptors. The typical factors contributing to contamination mobility may include: liquids with low viscosity, gas or volatile liquids, soluble substances, and particulate dust or sediments. These substances can be migrated through groundwater flow, drainage system, vapour, or dust emission. Usually, the mobility of heavy metals (e.g. lead and arsenic) will be depended on the soil pH. The light and volatile organic compounds are more mobile in water due to their solubility. On the other hand, these high volatility and high solubility substances can also be attenuated and degraded rapidly, which means they are not persistent in the contaminated land (Ministry for the Environment, 2004).

In addition, the contamination characteristics should be identified both vertically and horizontally (e.g. at surface or at depth, or widely-spreading or at a small volume). The understanding about the relationship of contamination to the geology and hydrogeology is essential (Murray, 2008).

2.5. Potential contaminant pathways and risk of receptors

The assessment of contamination pathways is to measure the possibility of a receptor to contact with the contaminants. In this case, there are mainly four parameters used to assess the pathways: containment, drainage system, groundwater pathway, and direct contact pathway, which will be assessed separately (Ministry for the Environment, 2004).

Containment

Containment is to measure the possibility of hazardous substance leakage from the petroleum and gas pipelines, and from the inappropriate installation of dangerous goods. This risk is mainly depended on the engineering structure of pipelines. If there is a double-skinned structure in the petroleum and gas pipelines, which have little potential of leakage, then this site will be considered as 'fully containment'. However, in 1940s, a toxic level of contaminants was likely to be released from the tar tank, tar pipelines, and tar storage & sales, so this site should be considered as 'no containment' in the past (Ministry for the Environment, 2004).

Drainage

In this case, another potential contaminant migration is through the stormwater drainage system. This drainage type may lead contaminants to be transported into surface water streams, such as river (Ministry for the Environment, 2004).

Groundwater

Groundwater pathway is of significance in this case. The risk of this pathway will be depended on the thickness of protective aquifer layer and the distance to the nearest groundwater uses. These uses can be either groundwater abstraction or discharge into surface water streams. Usually, the less permeable and deeper aquifer leads to lower risk of groundwater contamination. The good quality pavement on the ground is quite beneficial. Compared with aquifer thickness, the horizontal distance between contaminated site and the nearest user will determine the potential contaminant migration to the point of groundwater use through the aquifer, which potentially contacts with the receptors. Usually, the longer distance leads to lower risk. However, the distance that provides satisfied protection for the surrounding users is largely depended on the permeability of aquifer. Usually, only a relatively short distance (>100 m) is required for the clay and silt aquifer (low permeability) to successfully prevent contaminants from migration to the groundwater use point, compared with the sand and gravel soil which have high permeability. However, the most common aquifer type in Auckland region are basalts (fractured rock), which are considered as high permeability materials. It is suggested that the distance that is able to provide satisfied protection for basalt aquifer should be more than 1500 m. Therefore, the groundwater use should be considered as a potential risk in this case (Ministry for the Environment, 2004).

Direct contact pathway

Direct contact pathway includes dermal contact, and inhalation of volatile substances (e.g. hydrocarbons) or contaminated particulate matter. This risk is usually determined by the depth to hazard, surface cover, and soil permeability. Usually, if the hazardous substances are located at a depth of more than 4 m below the ground surface, then they are considered as low risk in the direct contact pathway. This risk can also be reduced by the surface cover and low permeability soil (Ministry for the Environment, 2004). However, in this case, there is a green garden within the contaminated site, which potentially facilitates the direct contact pathway.

Risk to receptors

In addition to the assessment of potential contaminant migration pathways, the risk for receptors to contact with the contaminated soil and water should also be assessed on the basis of site use and water use. Usually, both on-site and off-site assessment will be taken for the risk assessment. In this case, the contaminated site has been developed into residential apartments, which lead to a high exposure risk to the on-site residents through direct contact pathway. Another important consideration is groundwater taking, which can be used for drinking water (human and stocks), recreation, or crop irrigation. For example, if the irrigation water in the Victoria Park is taken from the groundwater at a point of short distance to the contaminated site, then it becomes another potential risk to the receptors on this recreational park. Further more, both the residential land use and recreational water use are usually ranked as the high risk types (Ministry for the Environment, 2004). In addition, the contaminants that are transported into surface streams by stormwater drainage system can be accessible to the environmental receptors in freshwater and coastal ecosystems.

3. Assessment of remedial methods and technologies

3.1. Cleanup criteria for contaminated site remediation

'How clean is clean enough for remedying a contaminated site?' Setting up environmental standards or cleanup criteria is the first step of assessment of remedial methods. There are some environmental guidelines for the remedial works, e.g. MfE Guidance documents. However, the objectives for each contaminated site remediation should be site-specific. Usually, there are a number of factors influencing the establishment of remediation objectives, including: nature of contaminants and the risk level involved; populations potentially affected; migration and exposure pathways; extent to which human health, safety, and welfare may be affected through exposure to site contaminants; types of contamination effects on the environment; site-specific characteristics influencing exposure; current and future uses of contaminated land; variability in exposure scenarios; regulation requirements and guidelines (Kofi, 2005).

3.2. Assessment framework and criteria

Usually, there is no universal remediation technique that is the optimal for all the types of contamination sites. The assessment of alternative remediation methods should be taken on a general basis, which mainly includes effectiveness, implementation, and cost. This evaluation process is generally more qualitative. However, the quantitative site characterization data are also used for the analysis. Particularly, the important contaminant properties must be paid great attention, including: retardation of contaminants; adsorption properties of compounds in solids; volatility of compounds; Henry's law constant (for air strippers); solubility; water partition coefficient; specific gravity; and degradation rate (Kofi, 2005).

In general, the evaluation criteria for the alternative remediation methods and technologies should include: protection of human health and the environment; both short term and long term effectiveness; compliance with regulatory standards; reduction of contaminant toxicity, mobility, and volume; technical and administrative implementation; cost effectiveness and efficiency of plans; amount of contaminated media; state acceptance; and community acceptance. In addition, the risk of remediation methods should be also taken into account, e.g. the contaminants may be transported into unaffected environmental matrices, or the remedial technologies themselves may cause contamination on the site, which is associated with residual after remediation action. Based on these criteria, the variety of remedial methods and technologies that are considered to be applicable will be assessed below. However, remediation for contaminated soil and groundwater will be discussed separately in this essay (Kofi, 2005).

3.3. Assessment of alternative remedial methods and technologies

Usually, the variety of remedial alternatives for contaminated site can be divided into four groups: natural process (volatilization, biodegradation, leaching, photolysis, and redox to destroy or attenuation of the contaminants); on-site isolation or containment; removal and disposal of contaminants to elsewhere (however, the same contamination problem may occur in the disposal site); and on-site and/or off-site treatments of contaminants and restoration of contaminated site, which involve physical treatment, chemical treatment, biological treatment, and thermal treatment (Kofi, 2005). However, a combination of several remedial methods is usually required to achieve the overall efficiency and effectiveness.

3.3.1. Excavation of contaminated soil

Usually, soil excavation is the initial step of many remedial methods. However, before excavation, the 'hot spots' that are shallow and highly contaminated in contaminated site should be firstly identified. Especially, if there are only small volumes of 'hot spot' in a vast land, then the excavation of 'hot spots' and disposal at a regulated landfill is a preferred option. This is more economy and faster than extensive soil excavation which also increases the exposure risk to on-site workers. However, the long-term monitoring is required (Kofi, 2005).

3.3.2. Soil vapor extraction

Soil vapor extraction (SVE) is used to remove volatile organic chemicals (VOC) in subsurface zones by enhancing soil aeration. In this process, a vacuum system pulls large volumes of air through contaminated soil, which disrupts the equilibrium between contaminant in soil and in vapor, and hence stimulates the airflow of vapor-phase VOCs out of soil pore spaces (Kofi, 2005). However, it is suggested that soil vapor extraction design based on critical pore-gas velocity (CPGV) is more effective than the design based on gas pressure criteria (Dixon & Nichols, 2007).

Soil vapor extraction can be easily applied by using standard equipments, whose effectiveness has been demonstrated at both pilot and field scale. Usually, volatile organic chemicals (VOC) can be well mitigated by soil vapor extraction. This is also a low-cost process (only $15-$185 per cubic meter). Soil vapor extraction minimizes the disturbance of contaminated soil during remedial process, and there is a potential for product recovery (Hutzler, Murphy, & Gierke, 1991). However, the effectiveness of soil vapor extraction is strongly depended on the geology and hydrogeology characteristics, e.g. in very shallow areas, the venting and emissions are difficult to be controlled; SVE is not effective below groundwater table; and soil vapor extraction process usually takes a long duration in fine-grained soils. The average time frame for soil vapor extraction is 1-10 years (Kofi, 2005). Particularly, soil vapor extraction is usually applied in conjunction with air sparging technology, which is the highly controlled injection of air into the contaminated soil saturation zone. The contaminants in the groundwater can be volatilized by the air bubbles. Then these volatile contaminants are transported into soil vadose zone and captured by subsequent soil vapor extraction. The combination of soil vapor extraction and air sparging can effectively remedy the VOC contamination in both soil and groundwater at difficult cleanup site (Dixon & Nichols, 2007; Kofi, 2005).

3.3.3. Chemical fixation

Chemical fixation (stabilization) is to chemically modify the structure of contaminants by adding specific reagents, which can be applied to a wide variety of organic and mental contamination. Immobilization of on-site contaminants is also essential in this chemical fixation process, which prevents contaminants from migration into unaffected site (Kofi, 2005; Yeh, Sachdev, & Singerman, 1990). For the chemical reagent, the improved two-part and inorganic chemical system which reacts with polyvalent metal ions and other waste components can effectively reduces heavy metals in contaminated soil (a reduction of heavy metal concentration by 96-100%). Further more, the chemical reagent itself produces a chemically and physically stable solid material, which is environmentally friendly (Porretta, Silverman, & Lo, 1990).

Chemical fixation can be applied to a broad range of contaminants, and is a relatively fast process, which takes up to 1 month to complete remediation. However, chemical fixation is a high-cost method, which requires $130-$390 per cubic meter. Long-term monitoring is required and future land use may be restricted (Kofi, 2005).

3.3.4. *In situ* soil flushing

In this process, the injected flushing agent, which is a biodegradable nontoxic surfactant, percolates into the contaminated soil and enhances the transport of contaminants to groundwater extraction wells in the down-gradient. Then the groundwater that contains contaminants will be collected for treatment, recycling, and disposal (Kofi, 2005). However, the selection of efficient surfactant is of significance. For example, an anionic/nonionic mixed surfactant (e.g. sodium dodecyl sulphate (SDS) mixed with Triton X-100) have been proven that they are efficient for the desorption of phenanthrene (Zhou & Zhu, 2007).

Usually, *in situ* soil flushing can be applied for remedying most organics and inorganic contaminants, and is a cost-effective process (only $25-$160 per cubic meter). However, the efficiency of this method is strongly influenced by site hydrogeology characteristics. *In situ* soil flushing is less feasible for complex contaminant mixtures. In this process, the leachate collection and treatment will also potentially increase the contamination risk to environment (Kofi, 2005).

3.3.5. Solvent washing/soil washing

In this process, contaminated soil is excavated and placed into water or other aqueous solutions. Then the contaminants are washed out by solvent recirculation through soils.

Solvents are selected according to the contaminant solubility and their environmental effects (Kofi, 2005). However, soil types play an important role in soil washing. Clay and silt soil usually tends to decrease the effectiveness of this method. It is suggested that the clay and silt contents should be less than 30% of total soil weight for solvent washing application (Pearl, Pruijn, & Bovendeur, 2006). For the washing of waste oil, a number of aqueous solutions can be applied, including aescin, lecithin, rhamnolipid, saponin, and tannin. However, their effectiveness is strongly depended on the washing temperature. It is suggested that a temperature of more than 50°C is required for these aqueous solutions (Urum, Pekdemir, & Copur, 2005).

Solvent/soil washing is commonly used for remedying soluble organics and metals. The remediation cost for solvent washing is relatively low. However, the waste solvent that contains contaminants requires treatment before disposal (Kofi, 2005).

3.3.6. Encapsulation

Encapsulation is to physically isolate the contaminated materials from the contamination site. Then containment of the contaminated materials is taken in a well-engineered landfill, which includes the use of low-permeability caps, slurry walls, grout curtains, and cut-off walls. After removal of contaminants, the low-permeability layers of synthetic textiles or clay caps, which prevent leaching and migration of contaminants, are installed to isolate the contamination sources (Kofi, 2005). Sodium silicate is the common material for encapsulation, which should be used in conjunction with shredded-tire particles for immobilization of contaminants in soil (Arocha, McCoy, & Jackman, 1996).

Encapsulation can be applied to remedy most chemical contaminants that do not attack containment materials. Usually, this method is preferred in open areas. It is relatively cost-effective and a remediation cost of $40-195$ may be required for per cubic meter treatment. However, encapsulation does not destroy chemical contamination so that this solution may not be permanent. The long-term monitoring is required to ensure the effectiveness of on-site containment (Kofi, 2005). I think encapsulation can be applicable as the final step of remediation program.

3.3.7. Landfarming

In landfarming process, the contaminated materials are excavated and spread over a large landfill area so that the natural occurring process (such as volatilization, aeration, biodegradation, and photolysis) can be enhanced for contaminant remediation. For the landfarming design, a low-permeability liner material is usually installed under surface to prevent leaching. The erosion and runoff during rainstorm conditions can be prevented by surrounding berms. The periodic applications of nutrients (such as phosphorus and nitrogen), moisture control, and oxygen exposure are generally required for the landfarming process (Kofi, 2005). However, it is suggested that landfarming should be designed in conjunction with other beneficial land use (e.g. biomass production, or landfills), because the long duration (10-15 years) of biodegradation process leads to a low economy (Harmsen et al., 2007).

Landfarming process is most suitable for lighter organic compounds. Usually, it is a cost-effective method (only $15-$50 per cubic meter). However, the efficiency of landfarming is restricted by the temperature (warm temperature is essential). A large land is required for landfarming. The particulate emissions that contain contaminants during landfarming process are difficult to be controlled, and landfarming process may not be able to achieve low levels of cleanup standards (Kofi, 2005).

3.3.8. Bioremediation

Bioremediation is a reliable method for remedying petroleum and aromatic hydrocarbons, chlorinated solvents, and pesticides. Microorganisms (especially bacteria and fungi) play an essential role in bioremediation process, which survive in soil and groundwater and assimilate these hazardous compounds, converted into innocuous or less toxic metabolic products. There are several factors influencing the bioremediation process, including temperature, types of compounds, dissolved oxygen levels in soil and groundwater, soil moisture content, soil permeability, oxidation-reduction potential, soil pH, compound concentrations, availability of nutrients, and the natural microbial community. Bioventing technology, which delivers oxygen into unsaturated soils, is generally applied to stimulate biodegradation. Usually, there are three types of bioremediation process: natural *in situ* bioremediation (relying on indigenous microorganisms without artificial manipulation); biostimulation (addition of selected nutrients to indigenous bacteria to stimulate biodegradation of targeted contaminants); and bioaugmentation (selection of special bacteria cultures to metabolize the target compounds) (Kofi, 2005; Zheng et al., 2006).

Bioremediation is generally most cost-effective method for large amount of contaminated materials, and the remediation cost ranges from $15 to $195 per cubic meter. However, this process will be most applicable, when most of contaminants extend into groundwater below surface. Intensive labor and maintenance are required. Biodegradation process may be eliminated when there are certain chemicals or low pH in soil. Biodegradation usually takes a relatively long duration (an average of 1-10 years) to complete remediation. In addition, the on-site contaminants may be transmitted into unaffected land (Kofi, 2005).

In this case, biodegradation is applicable for remediation of hydrocarbon, waste oil, phenols, and heavy metals (e.g. lead). I think the shortening of biodegradation duration becomes an important issue in the city area. For the bioaugmentaton process, selection of competent bacteria species is of significance for remedial efficiency and effectiveness. For example, the suspended and immobilized S. chlorophenolica PCP-1 cells can effectively remedy pentachlorophenol (PCP) contamination in groundwater, without applying additional nitrogen and phosphate nutrients in batch conditions (Yang & Lee, 2008). However, if remediation plan mainly relies on indigenous bacteria, then the selection and application of advanced substrates that stimulate biodegradation is essential (Wilson, 2007).

For the selection and cultivation of competent bacteria for the environmental remediation, some new improvements on bacteria classification method is designed in my another article (Liu Huan, 2021a), with a new cultivation method proposed for better environmental adaptiveness of microbes (Liu Huan, 2021b). Further more, a natural gene engineering procedure is designed to modify the microbial gene sequences for the selection of gene traits that are applicable on the environmental remediation and pollution control (Liu Huan, 2021c).

3.3.9. Asphalt batching

Asphalt batching can be applied to remedy hydrocarbon contamination soils. In this process, the petroleum-laden soils are incorporated into hot asphalt mixtures, which are used as a partial substitute for stone aggregates. The more volatile hydrocarbon contaminants will be volatilized during heating process, and the remainder of the hydrocarbon compounds will be incorporated into the asphalt matrix during cooling process, which hence prevents constituent migration when these stone aggregates are used for paving (Kofi, 2005).

Asphalt batching can achieve valuable economy for large volumes of contaminated materials (in this case, the contaminated site is relatively small), and it is estimated that a remedial cost of $40-$105 is required for per cubic meter. This method will have large economic value, only when large volumes of contaminated materials are required for treatment. Another advantage is the relatively short duration for remediation (only 1-3 month). However, the application of this new technology is restricted by the soil types (clay soils are not suitable for asphalt batching), contaminant types (mainly suitable for hydrocarbon contaminants), and meteorological factors (asphalt plants do not operate during cold weather). The offsite transportation may be required, which increases remedial cost (Kofi, 2005).

3.3.10. Incineration

Incineration is a thermal treatment, which destroys or volatilizes the contaminants by exposure to excessive heat in a variety of incinerator types. The contaminant residual in ash can be disposed in landfills (Kofi, 2005).

Incineration can be applied to a broad variety of organic compounds. It is also a fast process (1-3 months). However, incineration usually requires a relatively high cost ($50-$350 per cubic meter), and the economy of incineration can be achieved only when large volumes of contaminants are treated (in this case, the contaminated site is relatively small). The residual ash that may contain toxic level of contaminants requires further treatment before disposal (Kofi, 2005).

For example, in electroplating industry, wastewater generated from electroplating and acid-alkali washing process usually contains heavy metals at toxic level (Chen et al., 2001), such as Cu, Ni, and Cr (Table 1).

Table 1. Average chemical composition of electroplating sludge collected from 10 electroplating factories in Dong Guan City, China PR . Source from Chen et al., (2001).

Ingredient	Cu	Ni	Cr	Mg	Zn	Ca	Other	total
Mass composition (%)	14.64	13.27	2.16	0.60	0.30	13.50	55.53	100

Chemical precipitation process, which is commonly used for the removal of dissolved metals from electroplating wastewaters, leads to secondary pollution of electroplating sludge (Asavapisit & Chotklang, 2004; Chang et al., 2008), a hazardous waste classified by China National Standards of Environmental Protection (HJT 298-2007). Common treatment methods of electroplating sludge include heavy metal recovery, land-filling, ocean-dumping, incineration, stabilization or solidification etc (Shapouri et al., 2007; Chen et al., 2008; Dutra et al., 2008; Naim et al., 2010).

Tang et al., (2011) indicated that the hazardous copper could be stabilized crystallochemically into more durable copper aluminate spinel (CuAl2O4) structure by sintering simulated copper-laden sludge with aluminum-rich ceramic precursor. The optimal sintering temperature for CuAl2O4 formation was found to be approximately 1000℃, and corundum precursor led to the highest efficiency of copper stabilization, compared with γ-Al2O3, kaolinite and mullite precursors (Tang et al., 2011).

Shin et al., (2006) found that nickel-laden sludge could be crystallochemically sintered into the nickel aluminate spinel (NiAl2O4) which was identified as the stabilization phase for nickel. The crystallochemical efficiency was more than 90% at above 1250℃ with 3-h sintering (Shin et al., 2006).

Additionally, Ku et al., (2003) revealed that thermal treatment at higher temperature (1073K) decreased Cr(IV) species in Cr-laden sludge, and correspondingly increased the crystallinity of Cr(III) species which were less toxic. Cheng et al., (2005) also identified similar results in their thermal stabilization of Cr/sludge experiment. Cr(III) became the predominant species when the electroplating sludge were sintered at 1100℃ for 4-h (Cheng et al., 2005).

Overall, thermal treatment can be effective in terms of stabilizing heavy metals in sludge, and the optimal sintering temperature are generally above 1000℃, as illustrated above. However, so far seldom studies have investigated thermal stabilization of heavy metals in electroplating sludge which contains multiple heavy metal species.

A number of studies have investigated the feasibility of utilizing sewage sludge as an addition to construction materials, such as brick. Weng et al., (2003) indicated that the sludge proportion and firing temperature were two main determinants influencing the quality of bricks. Increasing the sludge proportion usually decreases brick shrinkage, water absorption capacity (Weng et al., 2003; Jorda´n et al., 2005), and compressive strength (Weng et al., 2003; Ingunza et al., 2011). Ingunza et al., (2011) concluded that 20% was the maximum proportion of sludge that could be added to the brick materials, in order to meet the technical requirements of construction brick. Weng et al., (2003) suggested that 10% sludge with 24% of moisture content prepared in the molded mixture could be good condition for manufacturing good quality bricks, and the optimal firing temperature was at 880–960℃. Nevertheless, to date few studies have investigated the utilization of electroplating sludge as an addition to construction materials.

To stabilize the heavy metals, it can be concluded that higher firing temperature is required for sintering electroplating sludge than sewage sludge, and corundum precursor should be more effective than γ-Al2O3, kaolinite and mullite precursors.

3.3.11. Groundwater extraction

Groundwater extraction is usually the first step for the restoration of contaminated groundwater. In this process, groundwater is pumped out and then treated either on site or off site. However, the disposal of treated water must meet certain pollutant discharge standards, and the contaminants that are released into atmosphere usually require air pollution control devices (Kofi, 2005).

3.3.12. Air stripping

Air stripping is to physically remove the dissolved-phase contaminants that are more soluble in air than in water. In this process, contaminated water is pumped from the ground and placed over packing materials in an air stripping tower, in which clean air is circulated. Then the contaminants tend to volatilize from the water into the air. The contaminated air is subsequently released into a granular activated carbon (GAC) system, or disposed into the atmosphere (Kofi, 2005). However, it is suggested that air stripping technology is difficult to achieve low levels of contaminant standards. Therefore, a combination of air stripping and other technologies (e.g. bioremediation) is required to reduce the groundwater contamination to a satisfied level (Kim, Hyun, & Lee, 2007).

Air stripping is usually applied to volatile organic compounds in groundwater. This simple technology is less cost ($15-$185 per cubic meter). However, the disposal of contaminated gas leads to atmosphere contamination, which requires the collection and treatment systems (e.g. GAC). This increases the maintenance cost (Kofi, 2005).

3.3.13. Activated carbon adsorption

In activated carbon adsorption process, granular activated carbon (GAC) is packed in vertical columns, which adsorb certain organic constituents when contaminated water flows through GAC. Contaminated water may be passed through several columns to complete contaminant removal, which is a highly effective process. Even very low concentrations of dissolved organics can still be removed by this technology. This method is commonly used for aquifer restoration (Kofi, 2005).

Activated carbon adsorption can be applied to a wide range of organic contaminants, and is a very cost-effective technology (only $15-$25 per cubic meter). This simple technology is also a fast process, and takes only up to 1 month to complete remediation. However, the device of granular activated carbon (GAC) requires frequent regeneration of carbon, and the disposal of waste carbons, which adsorb a large amount of contaminants, increases the maintenance cost (Kofi, 2005).

3.3.14. Other methods

There are also some other potential remediation methods for contaminated soils, including passive remediation (mainly relies on natural process) and phytoremediation. However, in this case, both passive remediation and phytoremediation are not feasible in city area, due to their long duration to complete remediation (Kofi, 2005; Koopmans, et al., 2007).

4. Conclusions and recommendations

Setting up a conceptual site model is usually the first step for the contaminated site investigation. In this model, identification of site geology and hydrogeology characteristics is of significance, which strongly influences the contaminant migration pathways. Especially, the aquifer features, groundwater flow, and hydrology budget have a profound effect on the groundwater pathway of contaminants. A study of site history is necessary for the identification of contaminants. The characterization of contaminants usually includes toxicity, mobility, and extent/quantity. Contaminant pathways largely determine contamination risk to receptors. The parameters used for the assessment of contaminant pathways usually are: containment of contamination sources, drainage, groundwater pathway, and direct contact pathway. However, the assessment of risk to receptors should also consider the types of land use and water use. In this case, the toxic contaminants may include heavy metals (e.g. lead, mercury, and arsenic), acids and alkalis, and petroleum hydrocarbons, and the groundwater pathway, direct contact in residential gardens, and stormwater drainage are potentially the main migration pathways of contaminants. The on-site residential land use and adjacent recreational water use may increase the contamination risk to receptors.

Usually, the effectiveness, implementation, and cost are the main considerations for the assessment of alternative remediation methods and technologies. However, the duration of remediation process should be also considered as an important part of economic ‘cost’, especially in the city area. Based on these criteria, there are a number of remedial methods and technologies that are identified to be applicable for the contaminated land and groundwater. Firstly, identification of ‘hot spots’ is beneficial for the excavation of contaminated soil. Chemical fixation is applicable. The improved chemical reagents can effectively destroy and immobilize the chemical contaminants. *In situ* soil flushing is an effective option. The anionic/nonionic mixed surfactant can largely improve the efficiency of contaminant desorption process. In the soil washing process, most of petroleum hydrocarbon contaminants can be well mitigated. For the waste oils, a number of aqueous solutions can be applied (e.g. aescin, lecithin, and rhamnolipid). The attractive advantage of soil vapor extraction is the minimal disturbance of contaminated site. A combination of soil vapor extraction and air sparging can effectively mitigate the contaminated soil and groundwater. Groundwater extraction is usually the first step of groundwater remediation. Air stripping and activated carbon adsorption are the common methods that have been proven to be effective for the water remediation. Bioremediation may be applicable. However, the selection of competent bacteria species and remedial substrates is of significance for the improvement of bioremediation efficiency. Usually, a combination of several remedial methods and technologies is beneficial for the optimization of effectiveness and efficiency.

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