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PERSISTENT ORGANIC POLLUTANTS: CONTAMINATED SITE INVESTIGATION AND MANAGEMENT TOOLKIT

Hasahisa, Sudan (Photo by Eisa Abdellatif,2009)

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Acknowledgements

What you will find in this toolkit

INTRODUCTION

The substantial improvement in the well-being of the world's population in the last century was largely driven by unprecedented scientific and technological progress. However, the economic processes and the scientific and technological progress that have underpinned these positive developments have been accompanied by significant negative externalities (adverse spill-over effects), which have continually posed major risks to human health, the environment and overall sustainable development.

Arguably, one of the dilemmas of modern development is the unfolding, but not well-understood, health and environmental consequences of increasing human dependence on organic chemicals. The chemical burdens, partly highlighted by persistent organic pollutants (POPs) and other products and by-products of the emergent "chemical society," have become potent sources of environmental and health hazards. The increasing presence of toxic chemical substances and wastes in production and consumption processes and the environment, and their potential for short- and long-term adverse impact on human life and other living organisms, have raised public concern in both developed and developing countries.

BACKGROUND ON POPs

POPs are resistant to environmental degradation through natural chemical, biological and photolytic processes. They can be conveyed for thousands of miles through air or water currents, and may be found in remote ecosystems far from their source, even in locations where POPs have never been used. Through bioaccumulation, animals higher in the food chain and humans are more likely to have higher concentrations of these pollutants, often to the degree that they, as endocrine disruptors, may cause neurological and immune system disorders as well as malignancies.

The Stockholm Convention on Persistent Organic Pollutants is a legally binding multilateral environmental agreement intended to protect human health and the environment from POPs. The Stockholm Convention was signed on May 23, 2001 and entered into force on May 17, 2004. The Convention requires the 160 countries who have signed it to reduce or eliminate 12 known POPs; the so-called dirty dozen (see Table 1).

The Stockholm Convention emerged in 2001 as evidence of the scientific consensus and, global public concern on the use and disposal of these 12 toxic chemicals. Notably, eight of these chemicals are pesticides and fungicides that are in common use in many developing countries, while two are industrial chemicals and two are common industrial by-products. Many of these pesticides played a significant role in past insubstantially increasing the world's food production and greatly reducing the post-harvest losses in developing countries through pest and plant disease management and control. In the fourth meeting of the Conference of the Parties held in Geneva on May 4-8, 2009, nine new POPs (see Table 2) were identified and added to Annexes A and B of the Convention (which require the elimination and restriction of POPs, respectively) for further global action.

Table 1
12 POPs identified by the Stockholm Convention, May 2001

Chemical	Annex (*)	Chemical name	Synonyms and Trade Names
Aldrin[1]	A	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4:5,8-dimethanonaphthalene	Aldrec, Aldrex, Aldrex 30, Aldrite, Aldrosol, Altox, Compound 118, Drinox, Octalene, Seedrin
Chlordane[1]	A	1,2,4,5,6,7,8,8-Octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methano-1H-indene	Aspon, Belt, Chloriandin, Chlorkil, Chlordane, Corodan, Cortilan-neu, Dowchlor, HCS 3260, Kypchlor, M140, Niran, Octachlor, Octaterr, Ortho-Klor, Synklor, Tat chlor 4, Topichlor, Toxichlor, Veliscol-1068
DDT[1]	B	1,1'-(2,2,2-Trichloroethylidene)bis(4-chlorobenzene)	Agritan, Anofex, Arkotine, Azotox, Bosan Supra, Bovidermol, Chlorophenothan, Chloropenothane, Clorophenotoxum, Citox, Clofenotane, Dedelo, Deoval, Detox, Detoxan, Dibovan, Dicophane, Didigam, Didimac, Dodat, Dykol, Estonate, Genitox, Gesafid, Gesapon, Gesarex, Gesarol, Guesapon, Gyron, Haveroextra, Ivotan, Ixodex, Kopsol, Mutoxin, Neocid, Parachlorocidum, Pentachlorin, Pentech, PPzeidan, Rudseam, Santobane, Zeidane, Zerdane
Dieldrin[1]	A	3,4,5,6,9,9-Hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-2,7:3,6-dimetanonapth[2,3-b]oxirene	Alvit, Dieldrite, Dieldrix, Illoxol, Panoram D-31, Quintox
Endrin[1]	A	3,4,5,6,9,9,-Hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-2,7:3,6-dimethanonaphth[2,3-b]oxirene	Compound 269, Endrex, Hexadrin, Isodrin Epoxide, Mendrin, Nendrin
Hexachloro-benzene[1] [2] [3]	A, C	Hexachlorobenzene	Amaticin, Anticarie, Bunt-cure, Bunt-no-more, Co-op hexa, Granox, No bunt, Sanocide, Smutgo, Sniecotox
Heptachlor[1]	A	1,4,5,6,7,8,8-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methanol-1H-indene	Aahepta, Agroceres, Baskalor, Drinox, Drinox H-34, Heptachlorane, Heptagran, Heptagranox, Heptamak, Heptamul, Heptasol, Heptox, Soleptax, Rhodiachlor, Veliscol 104, Veliscol Heptachlor
Mirex[1]	A	1,1a,2,2,3,3a,4,5,5a,5b,6-Dodecachloroacta-hydro-1,3,4-metheno-1H-cyclobuta[cd]pentalene	Dechlorane, Ferriamicide, GC 1283
Toxaphene[1]	A	Toxaphene	Alltex, Alltox, Attac 4-2, Attac 4-4, Attac 6, Attac 6-3, Attac 8, Camphechlor, Camphochlor, Camphoclor, Chemphene M5055, chlorinated camphene, Chloro-camphene, Clor chem T-590, Compound 3956, Huilex, Kamfochlor, Melipax, Motox, Octachlorocamphene, Penphene, Phenacide, Phenatox, Phenphane, Polychlorocamphene, Strobane-T, Strobane T-90, Texadust, Toxakil, Toxon 63, Toxyphen, Vertac 90%
PCBs[3]	A	Polychlorinated biphenyls	Aroclor, Askarel, Asbestol, Bakola 131, Delor, Chlortextol, Hydol, Inerteen, Pyranol, Pyroclor, Phenochlor, Pyralene, Clophen, Elaol, Kanechlor, Saf-T-Kuhl, Therminol, Santotherm, Fenchlor, Apirolio, Sovol, Sovtol
Dioxins[3]	C	Polychlorinated dibenzopara-dioxins	
Furans[3]	C	Polychlorinated dibenzofurans	

Table 2
Nine new POPs added to the Stockholm Convention, May 2009

Chemical	Annex (*)	Chemical name	Synonyms and Trade Names
Alpha hexachlorocyclohexane[1] [2]	A	Alpha-HCH	1,2,3,4,5,6-hexachlorocyclohexane, alpha isomer , (1alpha,2alpha,3beta,4alpha,5beta,6beta)- 1,2,3,4,5,6-hexachlorocyclohexane; Alpha-1,2,3,4,5,6-hexachlorocyclohexane, Alpha-benzen hexachloride, Alpha-BHC, alpha-HCH, alpha-lindane; Benzene-trans-hexachloride, Hexachlorocyclohexane-Alpha
Beta hexachlorocyclohexane[1] [2]	A	Beta-HCH	beta-1,2,3,4,5,6-Hexachlorocyclohexane: beta-Benzenehexachloride, beta-BHC, benzene-cis-hexachloride; beta-HCH; beta-Hexachlorocyclohexane; beta-Hexachlorocyclohexane ; beta-isomer; beta-lindane; Hexachlorocyclohexane-Beta; trans-alpha-benzenehexachloride; betabenzenehexachloride
Chlordecone[1]	A	1,1a,3,3a,4,5,5,5a,5b,6-decachloro-octahydro-1,3,4-metheno-2H-cyclobuta-[cd]-pentalen-2-one	decachloropentacyclo (5.2.1.0'2,6.0'3,9.0'5,8) decan-4-one, Decachlorooctahydro-1,3,4-metheno-2H,5H-cyclobuta-[cd]-pentalen-2-one, Decachloroketone. Merex, ENT 16391, Curlone, Kepone® and GC-1189
Hexabromobiphenyl[2]	A	2,2',4,4',5,5'-hexabromobiphenyl	Hexabromobiphenyl, HBB; 1,1´-Biphenyl, hexabromo-Biphenyl, hexabromo; FireMaster,
Hexabromodiphenyl and heptabromodiphenyl[2]	A	Diphenyl ether, octabromo derivative (octabromodiphenyl ether, octaBDE), C-octaBDE	octabromobiphenyl oxide, octabromodiphenyl oxide, octabromo phenoxybenzene and benzene, 1,1' oxybis-, octabromo derivative
Lindane[1]	A	gamma, 1,2,3,4,5,6-hexaclorocyclohexane	gamma benzene hexachloride; gamma-BHC; Agrocide, Aparasin, Arbitex, BBH, Ben-hex, Bentox, Celanex, Chloresene, Dvoran, Dol, Entomoxan, Exagamma, Forlin, Gallogama, Gamaphex, Gammalin, Gammex, Gammexane, Hexa, Hexachloran, Hexaverm, Hexicide, Isotos, Kwell, Lendine, Lentox, Linafor, Lindafor, Lindagam, Lindatox, Lintox, Lorexane, Nexit, Nocochloran, Novigam, Omnitox, Quellada, Silvanol, Tri-6, Vitron.
Pentachlorobenzene (PeCB) [1] [2] [3]	A, C	Pentachlorobenzene	1,2,3,4,5-pentachlorobenzene; benzene, pentachloro-; quintochlorobenzene; PeCB
Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F) [2]	B	Perfluorooctane Sulfonate (PFOS)	1-Octanesulfonic acid, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro; 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonic acid; 1-Octanesulfonic acid, heptadecafluoro-; 1-Perfluorooctanesulfonic acid; Heptadecafluoro-1-octanesulfonic acid; Perfluoro-n-octanesulfonic acid; Perfluoroctanesulfonic acid; Perfluoroctylsulfonic acid
Tetrabromodiphenyl ether and pentabromodiphenyl ether[2]	A	C-pentaBDE	

[1] Pesticides   [2] Industrial chemicals   [3] By-products   (*) Annex[1]

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[1] **Annex A:** Parties must take measures to **eliminate** the production and use of the chemicals listed under Annex A. Specific exemptions for use or production are listed in the Annex and apply only to Parties that register for them.
  Annex B: Parties must take measures to **restrict** the production and use of the chemicals listed under Annex B in light of any applicable acceptable purposes and/or specific exemptions listed in the Annex.
  Annex C: Parties must take measures to **reduce** the unintentional releases of chemicals listed under Annex C with the goal of continuing minimization and, where feasible, ultimate elimination.

PURPOSE OF THIS TOOLKIT

While the goal of effective management of POP-contaminated sites is a priority for the Stockholm Convention, the Convention does not cover the specifics of how to manage site contamination. Specifically, Article 6 of the Stockholm Convention, which describes measures to reduce or eliminate releases from stockpiles and wastes, states:

"1. …(e) Endeavour to develop appropriate strategies for identifying sites contaminated by chemicals listed in Annex A, B or C; if remediation of those sites is undertaken it shall be performed in an environmentally sound manner.

2. The Conference of the Parties shall cooperate closely with the appropriate bodies of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal to, inter alia: …

(c) Work to establish, as appropriate, the concentration levels of the chemicals listed in Annexes A, B and C in order to define the low persistent organic pollutant content referred to in paragraph 1 (d) (ii)."

Mindful of the need to deal with POPs, the United Nations Industrial Development Organization (UNIDO) Expert Group on POPs[2] has developed this comprehensive Toolkit. The Toolkit aims to aid developing countries with the identification, classification and prioritization of POP-contaminated sites, and with the development of suitable technologies for land remediation in accordance with best available techniques and best environmental practices (BAT/BEP). The Toolkit focuses exclusively on the 12 POPs listed in Table 1. The nine POPs recently added to the Stockholm Convention (listed in Table 2) are not discussed here because there are still significant scientific challenges and unknowns associated with them.

The Toolkit will be first adopted in Ghana and Nigeria as part of UNIDO's regional project on the development of strategies for identifying sites contaminated by chemicals listed in Annexes A, B and C of the Stockholm Convention. The Toolkit will be used both as a training tool and as a self-directed manual and resource document for decision-makers, practitioners and a range of other stakeholders. It is envisioned that the Toolkit may eventually be used throughout the whole African region and in developing countries in other parts of the world.

The UNIDO project in Ghana and Nigeria takes into account sustainability and reproducibility and above all incorporates regional context for future outreach activities. Lessons learned and experience gained will be useful in the systematic identification of POP-contaminated lands, risk assessment/prioritization and application of appropriate remediation technologies. UNIDO will also provide support by facilitating reports on case studies and pilot demonstration projects, and by producing further tools and protocols for use by the industrial sector, professionals and practitioners. Special attention will be given to capacity building and human resources development in an effort to reach a critical mass of national and regional experts.

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[2] The Expert Group on POPs included international experts from Asia, Africa, Europe and North America, all of whom have experience related to contaminated sites.

KEY FEATURES OF THE TOOLKIT

Here are some of the key design and content features of this Toolkit, which is the first document of its kind to offer such a comprehensive discussion of the various issues, strategies and processes associated with POP-contaminated sites.

Step-by-step approach: The Toolkit is designed to provide a clear step-by-step approach that can be easily followed and implemented by a variety of users.

Easy-to-use worksheets and checklists: The Toolkit includes various worksheets, tables, and checklists, currently used in developed countries, that users in developing countries can adopt, and then modify to meet their own needs.

Guidelines for site investigation: The guidelines for site investigation presented in this Toolkit may be its most important single contribution because, in general, developing countries have no locally derived standards for the assessment of land contamination. Since the process of developing guidelines from scratch is expensive and time consuming, developing countries need to start from somewhere and adopt standards from developed countries. Although the guidelines presented here may come from countries with different ecological and environmental conditions, they will still offer an adequate degree of human health protection to developing countries in the interim, during which time they can collect adequate ecological and environmental data that can ultimately be used to adapt the guidelines to their own local environment.

The Toolkit also includes two detailed case studies, which illustrate the successful implementation of these guidelines in Ghana and Nigeria.

Integration of risk assessment with contaminated site management: This Toolkit takes a unique approach to the management of POP-contaminated sites by integrating remediation strategy with technical, political, legal, social and economic considerations to develop risk reduction and prevention strategies. While a risk-based approach increases the time and effort spent up front and requires ongoing site monitoring, it can often lead ultimately to lower remediation costs. The steps involved in this type of approach are outlined in the Toolkit.

Screening levels for POPs: This Toolkit presents screening levels — limits for quantitatively evaluating risk levels for soil and groundwater — for the 12 POPs in Table 1. Since there is no single document source for these values, the authors of this Toolkit have extracted them, with a degree of difficulty, from a number of sources.

Screening matrix for selection of remediation technologies: The Toolkit presents an easy-to-use and simple screening matrix system that can be used for selecting the most appropriate remediation technology for a specific site according to the local situation. The application of this low-cost, time-saving tool is illustrated through three case studies.

Cost-benefit analysis: This toolkit also presents a step-by-step approach to economic analysis of POPs-contaminated sites. It is intended to provide practitioners with an understanding of cost structures and financing mechanisms for developing countries.

HOW THE TOOLKIT IS STRUCTURED

The Toolkit is divided into five main modules, as described below. Figure 1 illustrates how the content of the modules fits into the overall approach to POP-contaminated site management recommended by this Toolkit.

Module 1, Policy and Legal Issues, outlines the basic legal and policy issues for POPs, and explains the fundamental principles being used to set regulation and to develop criteria and permissible levels of POPs. Areas of discussion include site inventory initiatives, land acquisition and disposal, permissible levels of contaminants, toxic tort actions, risk-based remediation goals, and the key role of sustainability in site remediation. The module also covers how remediation can be facilitated by tax and non-tax incentives, institutional arrangements and inter-sectoral collaboration.

Module 2, Conducting a Site Investigation, provides guidelines for investigating a potentially contaminated site through two distinct phases. A preliminary site investigation (PSI), which is made up of two stages (PSI Stage 1 and PSI Stage 2), confirms whether a site is contaminated or not, and a detailed site investigation (DSI) delineates the extent of the contamination. The site investigation process is illustrated in case studies from Nigeria and Ghana.

Module 3, Assessing Site Risks, provides guidelines for assessing the human health risks of a POP-contaminated site. It outlines two different approaches to risk assessment. The generic Tier 1 assessment uses the information collected during the site investigation to compare contaminant concentrations against the recommended values for soil and groundwater. The more complex Site-Specific Risk Assessment identifies a site's contaminants, exposure pathways and receptors, which can then be used as the basis for developing a risk management process in situations when complete remediation is not a viable option for a contaminated site.

Module 4, Managing Contaminated Sites, provides guidance on developing a strategy for contaminated site management. It presents risk management options to assist users in selecting the best option for a specific site and a classification/categorization system for prioritizing sites for remediation, according to risk. The module introduces a simple screening matrix system as a low-cost tool to help in the selection of the appropriate technique for a specific site according to its local situation. The application of the screening system is illustrated through three case studies. The technology and limitations of different remediation techniques are summarized, and the module concludes with a discussion of post-remediation site monitoring requirements.

Module 5, Costing and Financing Site Remediation, provides guidance to analysts in the economic analysis of POP–related environmental policy issues. A carefully thought-out cost-benefit analysis of remediation options (as outlined step by step in this module), and the selection of the most appropriate financing mechanism, will greatly enhance the likelihood of success in the implementation of POP-contaminated site management and control policy.

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                    │ Contaminated Site Investigation, │
                    │ Identification, and Characterization │
                    │        (Module 2)             │
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                    │ Site Risk Assessment (Module 3) │
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   │ Costing  │◄ ─ ─│ Develop Remediation / Risk Management │
   │ Financing│     │ Strategy and Post-remediation         │
   │(Module 5)│     │ Monitoring (Module 4)                 │
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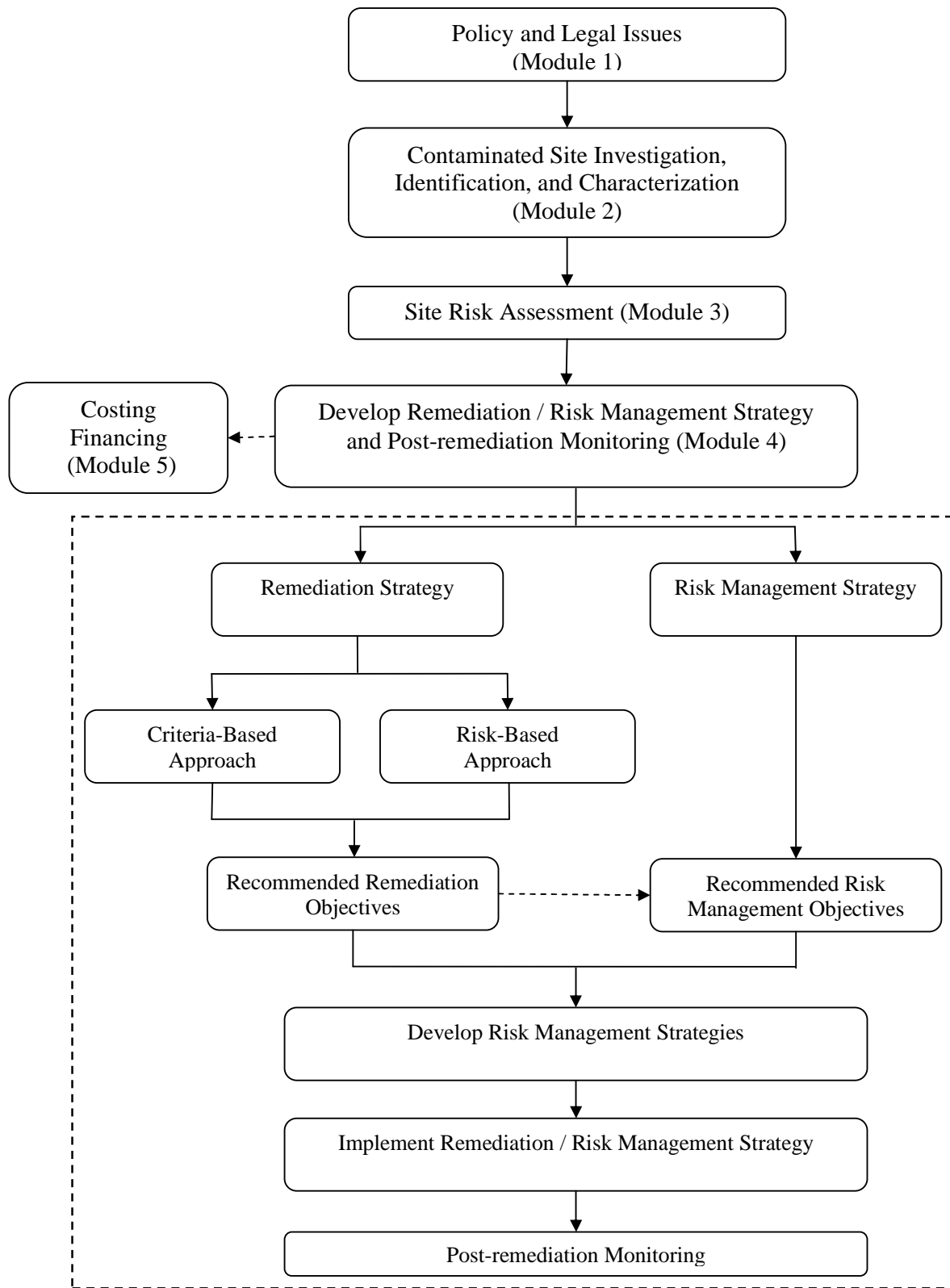

Figure 1
Recommended Approach to Contaminated Site Management

7

MODULE 1

POLICY AND LEGAL ISSUES

This module outlines the basic legal and policy issues for sites contaminated by persistent organic pollutants, and introduces some of the concepts discussed in the other four modules.

It explains the basic principles being used nationally and internationally to set regulation, and to develop criteria and permissible levels of contaminant concentrations, in an effort to protect the environment and human health.

1.1 INTRODUCTION

This module serves as a general introduction to this toolkit. It covers the basic legal and policy issues in relation to environmental pollution, with emphasis on persistent organic pollutants (POPs). Most countries have environmental policy, regulation and legislation to safeguard the well-being of their populations and to protect the environment. Environmental policy is designed to deter polluters and to recover the cost of restoring the environment or to compensate to those who have been suffered from the adverse effects of the pollutants. As the impact of pollutants on humans and the environment become better known, criteria or permissible levels of the chemical concentrations in the environment are set (pertaining to the presence of the chemical in the media: soil, air, water, sediment). Certain chemicals, such as POPs, are subject to international efforts to eliminate them.

Special attention is needed when a location that previously had industrial activities could have potential contamination. For example, gas works and old electricity generating stations are likely to be contaminated with PCBs because PCBs were components of transformer fluids. These sites could be polluted by one of the POPs. Even when the POP-contaminated site is cleaned up to permissible levels, there is a possibility that impacts on people and the environment will have caused long-term health effects and environmental damage. It is vitally important for the country to resolve the basic issues for POP-contaminated sites including their inventory, contaminated site discovery, and remediation.

Developing environmental policies, formulating regulations and putting them into legislation are costly and time-consuming. These measures must also evolve as we gain more understanding of the impact of POPs on human health and the environment. Many developed countries spent million of dollars over decades to put in place and enforce environmental legislation. For developing countries, carrying out such undertaking might be impossible. They can make use of what are available in their countries to set as references, and then establish clear goals to protect their environment. It must be borne in mind that chemical and environmental understanding is advancing every day. As we gain better understanding of the impacts of chemicals on humans and the environment, the criteria for chemical exposures will continue to be modified. Policies should also be updated accordingly.

It is of great importance for practitioners, government agents and environmental engineers in developing countries to gain understanding on various issues involved in the management of POPs-contaminated sites. This module is intended to provide understanding on the fundamental principles used to set regulations and develop criteria/permissible levels of POPs concentrations in an effort to protect human health and the environment. The precautionary principle is provided. We discuss as well the Polluter Pays Principal, which makes the former industry accountable. The significance of site inventories, land use and redevelopment, environmental compensation and liability are also discussed, because they are part of the overall environmental policy. This information is significant for practitioners and environmental government agencies in developing countries to assigning responsibility and liability for POP-contaminated land and in developing policy. It is important to determine whether or not the POP-contaminated sites need to be cleaned up, the basis for decision-make, the regulations governing such work, and why is it essential to keep good records.

In these respects, site inventory initiatives have a significant function throughout the process of land acquisition (reuse and redevelopment) and remediation/ decontamination of potentially-contaminated land. Levels of POPs permitted in environmental compartments

help in settling cases related to the law of torts and civil laws for compensation, as well as in setting risk-based remediation goals for POPs.

To clean up POPs contaminated site for the protection of human health and the environment, it is vitally important to carry out a proper site investigation (Module 2), followed by assessment of the risks of a given site (Tier 1 in Module 3), and then to decide whether to utilize a risk-management approach and/or to remediate the site (Site Specific Risk Assessment in Module 3 and Module 4). This information will help in building a national and international database of contaminated sites. Cost estimation and especially financing to clean up a given site is critical for developing countries (Module 5).

In this module, we also provide information on the use of tax and non-tax incentives, institutional arrangements and inter-sectoral collaboration issues to facilitate contaminated site remediation.

1.2   REVIEW OF ENVIRONMENTAL LEGISLATION AND POLICY

Historically, the regulation of pollution focused on contaminants that decompose in the environment, such as acids, oils, grease, and wastes from animal processing, with a primary goal of protecting human health and the environment. Locally developed regulations were either based on local studies and/or on modifying available resources from other countries.

Precautionary Principle

With the discovery of highly toxic, chemically stable, non-biodegradable pollutants that have the tendency to accumulate in living organisms, a brand-new approach to regulation has been adopted internationally. For example, a group of synthetic organic chemicals, characterized by multiple carbon-chlorine bonds, high chemical stability and high toxicity (such as persistent organic pollutants, POPs), has been clearly identified as an unusual and special class of risk. As a result, in 1987 representatives at the Second International Conference on the Protection of the North Sea adopted the so-called precautionary principle as part of international law for the first time. The conference agreed that the discharges of substances that are "persistent, toxic and have potential to bioaccumulate" should be prevented at source, "even when these is no scientific evidence to prove a causal link between emissions and effect" (Kriebel et al., 2001). The precautionary principle has become a guiding principle for the protection of the environment and human health in recent years. If used properly, it can support efforts to strive towards a healthier and safer world (Martuzzi and Tickner, 2004).

Polluter Pays

In environmental law the "polluter pays" principle is enacted to make the party responsible for pollution responsible for paying for the damage done to the natural environment or the land, thereby favouring a curative approach in repairing ecological damage and for remediating the contaminated site.
This principle was first introduced by the lawmakers of the U.S. state of New Jersey between 1976 and 1984 when they enacted the first mandatory site cleanup program based on the principle of "polluter pays." New Jersey's laws were the country's most encompassing and

restrictive state statutes regulating property transfers. Elements of the program have been widely adopted by other U.S. states (Day and Johnson, 2004).

Polluter pays is also known as extended polluter responsibility (EPR), a concept that was first described by the Swedish government in 1975. EPR seeks to shift the responsibility dealing with waste from governments (and thus, taxpayers and society at large) to the entities producing it. In effect, it internalizes the cost of waste disposal into the cost of the product, theoretically meaning that the producers will improve the waste profile of their products, thereby decreasing waste and increasing possibilities for reuse and recycling.

The Organization for Economic Co-operation and Development (OECD) defines EPR as "a concept where manufacturers and importers of products should bear a significant degree of responsibility for the environmental impacts of their products throughout the product life-cycle, including upstream impacts inherent in the selection of materials for the products, impacts from manufacturers' production process itself, and downstream impacts from the use and disposal of the products. Producers accept their responsibility while designing their products to minimize life-cycle environmental impacts and accepting relevant legal, physical or socio-economic responsibility for environmental impacts that cannot be eliminated by design" (OECD, 2006).

National Legislation and Policy

The precautionary and polluters pay principles have been integrated into the approaches taken by many developed countries to contaminated site issues and are being enforced by environmental agencies through legislation. Developed countries such as United States, Canada, Japan, Singapore, and United Kingdom have their own legislation on POPs, which varies greatly. In 2004 the European Union set common standards on POPs through Regulation EC No. 850/2004. Unfortunately, such legislation is not available in many developing countries to protect their people's health, even though the illegal disposal of POPs is common.

Developing countries that are among the 50 countries that ratified the Stockholm Convention in 2004 are tasked with developing National Implementation Plans (NIPs). These comprehensive strategic policy documents must outline how a particular country intends to eliminate POPs. NIPs aim to formalize an effective POP management system through the implementation of a sustainable policy to secure human health and environmental protection as defined in the Stockholm Convention.

An NIP may encompass the following:
- legislative and regulatory measures for the reduction and elimination of POP releases on a prioritized basis
- strengthening of sustainable administrative capacity
- strengthening capacity of the regulatory agencies for the enforcement and implementation of the Convention
- a POP communication strategy

The main objective of an NIP is to raise public awareness and, at the same time, strengthen the capacity of regulatory agencies to effectively protect human health and the environment

from the harmful effects of POPs, especially in developing countries that do not have comprehensive regulation, legislation or waste management acts to protect their environment.

1.3 CONTAMINATED SITE INVENTORY INITIATIVES

Creating and maintaining a public inventory of POP-contaminated sites is the first important step in the development of an NIP by a regulatory agency in a developing country. A contaminated site database is vital as a country develops, its population grows, and there are redevelopments of land and changes of land use. Since no standard database exists in the world, developing countries must use the database format of one of the developed countries, modifying it if necessary and continuously improving it over time. The inventory needs to cover information collected during the site investigation from Module 2 PSI Stage 1 and/or Stage 2. This information includes the site profile, past and present activities, spill releases, and site owners.

1.4 POLICY AND LEGAL ISSUES ASSOCIATED WITH LAND ACQUISITION

Land used for human activities (industrial, agricultural, commercial or residential due to urbanization) could potentially introduce anthropogenic contamination to the ground. In the case of land redevelopment due to urbanization, population growth, and industrialization, it is important for the potential buyer or government to exercise due diligence to find out whether or not the land is contaminated before it is redeveloped. Any transfer of industrial land raises the problem of possible contamination. According to the policy in many developed countries, once the buyer purchased the land, he/she, the owner is response for the clean-up if the land is contaminated and if there are off-site migrations to the neighbour's properties, the owner is also found responsible and legally liable in clean-up the neighbouring properties, in order to protect human health and environment. Therefore, for the protection of the buyer, they should exercise due diligence in finding the appropriate files and checking with the authorities' records and spill releases (See above Section 1.3). Normally, a lack of information at the early phase of the negotiations should lead the diligent operator to suspect that there exists a potential for contamination on the site. Other information on "risk-activities" obtained through aerial photograph reviews, site visits and interviews with landowners, occupants and/or current and past facility operators is also valuable (Preliminary Site Investigation of Module 2). In case of incomplete information, an in-depth site investigation (Detailed Site Investigation of Module 2), then environmental site assessment is recommended (Module 3). This is especially important if the transfer leads to a change in land use, for example from industrial to residential. If the land is indeed contaminated, a soil remediation plan has to be elaborated (Module 4). This is part of the environmental policy to protect the health of people who will be living in that land and developer/owner are legal responsible for ensure that the houses are not built on contaminated land. Of these processes, costing and financing are very important components and often constitute the biggest hurdle in dealing with POP-contaminated sites because of the technological challenges associated with high costs and resources. In this case, the developer has to weigh the costs and benefits of purchasing the land.

If the land is in the centre of a city, due to the potential risk to humans, the land will be ordered to be clean. It is common in developing countries for there to be a lack of definition

of land use. There are many operational and historic environmental risks associated with both past and present land use. Therefore, risks associated with the acquisition and disposal of potentially polluted land should be investigated.

With operational risks, it is important to distinguish between point sources and diffuse sources of contamination. Diffuse sources such as crop spraying can lead to the general degradation of the quality of soils, impact on surface water and groundwater, leading to biological uptake. However, such contamination is difficult to detect without the soil, vegetation, and biological sampling usually conducted in a Site-Specific Risk Assessment (see Module 3). Please note that point sources are usually more easily detected using standard due diligence techniques. These may include chemical stores, agricultural sites and waste disposal facilities. Land or buildings associated with such operations can usually be detected by inspection of historic maps, perusing environmental databases or, if necessary, with the aid of a site inspection. Historic risks include gas works and electricity generating stations, which one normally associates with large towns and cities (Alberta Environment, 2002).

For detailed discussions on the investigation of the risks associated with the acquisition and disposal of potentially polluted land, see Module 2, and for Tier 1 risk assessments based on contaminant concentrations, see Module 3.

1.5   PERMISSIBLE LEVELS OF POPs IN THE ENVIRONMENT

In developing POP-contaminated policy and regulation, a basic approach which considers the potential risk of the contaminants to human health is used to assess the potential risks to ecosystems and human health by toxic and other harmful effects of pollutants. This involves comparing observed concentrations of pollutants in the environment with established "maximum permissible levels" and "levels of concern" (values that trigger action) in corresponding media. There are a number of guidelines and other normative documents that provide values for such levels for various substances in different media. (These are discussed in Tier 1 of Module 3.)

Human beings interact with their environments and, as a consequence, are exposed to a broad spectrum of synthesized chemicals present in the food they eat, the air they breathe and the water they drink. With a view to protecting public health, regulatory agencies have set permissible levels of pollutants that should not be exceeded in the diet (see Site-Specific Risk Assessments in Module 3).

In establishing criteria upon which guidelines could be based, it became apparent to the health profession and human risk assessors that carcinogens (tumour-inducing chemicals) and non-carcinogens would require different approaches. These approaches are determined by theories of carcinogenesis, which postulate that there is no threshold for effects (that is, there is no safe or no observed adverse effect level). Risk managers are, therefore, faced with two choices: either to prohibit a chemical or to regulate it at levels that result in an acceptable degree of risk. Indicative figures for risk and exposure assist a risk manager to reach the proper decision.

Current understanding of toxicity of these compounds is based primarily on studies performed on laboratory animals exposed to a single toxic agent. The reported effects are seen, in all cases, at relatively high levels of exposure. The human population is ubiquitously

exposed to complex mixtures of these contaminants generally at much lower levels of exposure than those routinely examined in animal toxicity studies, and the effects of any interactions between such substances on their toxicity are virtually unknown. To estimate safe levels of exposure for any given compound for the human population, all available toxicity data for that compound are synthesized into a dose rate, which, theoretically, through a broadly accepted methodology, is the highest rate of exposure that can occur over a moderate length of time without causing any adverse health impacts. While this approach assumes that there is little interaction between chemical substances in their toxic effects or that the degree of any synergistic increase in toxicity will not exceed the safety factors applied, there have been relatively few studies that have tested these assumptions (Wade et al., 2002).

Unfortunately, in the case of POPs, the method applied to calculate the limits contains a number of uncertainties. Most importantly, for several POPs there may be no "safe" level at all. Permissible levels are available for all POPs belonging to the pesticide category, and data on polychlorinated biphenyls are listed in Erickson (1997). Recently, the EU established maximum permissible levels for human consumption of 4 and 8 ng/kg of toxic equivalents (WHO-TEQ), for PCDD/Fs and for PCDD/Fs plus dioxin-like compounds, respectively, in the muscle meat of fish and fishery products (EC Commission Regulation, 2006; Szlinder-Richert et al., 2009).

Some chemicals are members of the same family and exhibit similar toxicological properties; however, they differ in the degree of toxicity. Therefore, a toxicity equivalence factor (TEF) must first be applied to adjust the measured concentrations to a toxicity equivalent concentration (Van der Berg et al., 2006). Concentrations of POPs permitted in food and the environment are useful in settling cases falling in the ambit of law of torts and civil laws for compensation (discussed later in this module).

Permissible levels and methods of evaluation vary from country to country. It also cost multi-million dollars to develop such criteria. At this time, it is not likely that developing countries be able to afford such extensive studies in terms of cost and time. This toolkit summarized the permissible levels for all 12 POPs for references when developing countries are dealing with these POPs. See Module 3 for evaluations and sample calculations, based on information from Health Canada (2004a,b) and USEPA (1997). When the time is appropriate, the developing countries can develop their own permissible levels for various POPs according to the country's criteria and needs.

1.6   TOXIC TORT ACTIONS

In this section, we introduce the concept of "toxic tort" in environmental legal issues and stress the importance of environmental policy, regulation and legislation in protecting human health. This is directly related to Sections 1.2 to 1.5 above with respect to liability and responsibility. Due to knowing or unknown long-term exposure to pollutants, human health will have been affected. Subsequent compensation, response and liability are addressed through legal action, called "toxic tort actions". These help people who had been adversely affected to be compensated for adverse health impacts.

The term "toxic torts" encompasses a wide variety of claims, both private and public. Toxic tort actions involve highly diverse harms caused by diverse toxic chemicals. In the United States toxic torts include liabilities delineated in the Comprehensive Environmental

Response, Compensation and Liability Act. In general, the claims involve the release of and exposure to – or threatened release of and exposure to – one or more substances alleged to be "toxic." The definition of what is "toxic" may vary, depending upon the context in which it appears. According to a broad, workable definition, imminent hazard is described as involving "the manufacture, processing, distribution in commerce, use, or disposal of [a substance that] is likely to result in injury to human health or the environment." In general, in a toxic tort action, the full effects of exposure are not immediately apparent. This is either because the injury does not manifest itself immediately or because the harm goes undiscovered for a period of time. Injuries such as cancer, birth defects, and genetic mutations necessarily require a latency period for their development. Latency periods of ten to 30 years appear frequently in the cases.

The strongest evidence of causation in a toxic tort action is probabilistic evidence. Probabilistic evidence cannot establish that exposure to the substance was the actual cause of the particular plaintiff's injury. It merely deals in probabilities, never in certainty. The causation problem is one example of the role that risk plays in toxic tort litigation. Probabilistic evidence is based upon risk; that is, it provides the court or jury with evidence of the risk of developing a certain illness as a result of exposure to a particular substance. Statisticians skilled in the area of epidemiology have created models that estimate the level of risk of illness from exposure to a substance. Translating statistical risk into legally cognizable standards has, however, been problematic, and resistance to employing concepts of risk to form the basis of legal claims is pervasive (Eggen, 2005).

1.7   SETTING RISK-BASED REMEDIATION GOALS

POPs have adverse effects on human health. Therefore, POP-contaminated sites need to be properly managed or remediated. The newest approach to manage a contaminated site is integrated human health risk assessment into management of contaminated sites. Human health risk assessment is the characterization of the potential adverse health effects of human exposures to environmental hazards. Risk assessments can be either quantitative or qualitative in nature. The elements of a human health risk assessment include planning and scoping, acute hazards, evaluating toxicity, assessing exposures and characterizing risks. The human risk assessment is the focus of this Toolkit with further details outlined in Module 3. Due to the complexity of ecological systems, however, the ecological risk assessment is not dealt with in this Toolkit.

Within the U.S. Environmental Protection Agency (USEPA), waste and cleanup programs assist regulatory and program decisions in protecting human health and the environment from the risks of contamination and chemical accidents. The National Academy of Sciences Risk Assessment Paradigm forms the basis for risk assessment within USEPA's waste and cleanup programs. Existing policy, evolving research, and risk assessment advances converge to inform risk management decisions. Risk Assessment Guidance for Superfund provides guidance on the human health evaluation activities that are conducted during the baseline risk assessment – the first step of the Remedial Investigation Feasibility Study. The baseline risk assessment is an analysis of the potential adverse health effects (current or future) caused by hazardous substance releases from a site in the absence of any actions to control or mitigate these releases (i.e., under an assumption of no action). The baseline risk assessment contributes to the site characterization and subsequent development, evaluation, and selection of appropriate response alternatives (Tier 1 discussed in Module 3). The results of the

baseline risk assessment are used to help determine whether additional response action is necessary at the site, modify preliminary remediation goals, help support selection of the "no-action" remedial alternative, where appropriate, and document the magnitude of risk at a site, and the primary causes of that risk (EPA, 1989). Many countries are adopting similar processes to those of USEPA.

Site-Specific Risk Assessments (see Module 3) may vary in both detail and the extent to which qualitative and quantitative analyses are used, depending on the prevailing complexity and particular circumstances of the site, as well as the availability of applicable or relevant and appropriate requirements and other criteria, advisories, and guidance. After an initial planning stage, there are four steps in this risk assessment process: problem formulation (data collection and analysis); toxicity assessment; exposure assessment; and risk characterization. With the risk characteristics of the POP-contaminated site, we can develop strategic to manage and/or remediate site.

1.8 SUSTAINABLE REMEDIATION

A modern approach to achieve a healthy earth is in terms of environmental sustainability. Even though this is not part of any environmental policy or regulation, it is encouraged by environmental agencies in many developed countries in order to protect "mother earth." In remediating a POP-contaminated site, reuse of the land and restoration of the natural environment must be taken into consideration.

In 1987, the Brundtland Commission articulated what has now become a widely accepted definition of sustainability: "[to meet] the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Since then, the idea of sustainable human well-being has become increasingly associated with the integration of economic, social and environmental spheres. As a result, sustainability has become an important factor when polluted site remediation efforts are considered. This is especially true for the remediation of POPs, because of the persistence and high toxicity of these chemicals.

Based on the significance of sustainability, it is important to show the "green benefits" of the remediation methods (remediation technologies will be discussed in Module 4) to ensure that no hazardous by-products are generated in the remediation process, and that energy consumption and water usage are minimum. Most importantly, there should be minimal impact on local, regional and global environment such as air, water, soil and sediment. If at all possible, the remediation technique should generate no by-products which might harm human health or environment. After remediation, the land should be able to sustain living organisms and plant growth.

1.9 TAX AND NON-TAX INCENTIVES

How to finance the remediation of contaminated sites is an extremely important subject for developing countries where funding is always an issue (see Module 5 for further information on the selection of a financing mechanism.). The United States is a good example of a country that has developed a range of financing methods to help communities solve their

environmental problems. Unfortunately, there is limited information available on other countries.

In the United States, there are several types of tax incentives available to advance polluted site remediation efforts. These provide basic financing for site assessment and cleanup, along with the more complex planning and transaction costs that these sites usually require. The primary goals of the tax incentives are to offset remediation costs and/or to provide a buffer against increases in tax assessments (resulting from higher value of the decontaminated property) before the costs of remediation are paid off. For example, in 1998 the Florida Legislature created the Voluntary Cleanup Tax Credit, which allows eligible applicants to obtain up to 35 per cent of the costs of site remediation. In addition, the Brownfield Redevelopment Bonus in Florida encourages job creation in designated Brownfield areas through a tax refund of up to $2,500 for each new job, or 20 per cent of the average wage of the jobs created, whichever is less.

A different approach was used in 1996 in Michigan, where authorized cities and counties were allowed to use Tax Increment Financing (TIF) for remediation of polluted sites. Remediation increases the value of the site and generates increased tax revenues called "tax increments". In summary, TIF has created funding for public projects that localities might otherwise not have been able to afford. Property owners in Michigan may also apply for a Single Business Tax Brownfield Redevelopment Credit if it is included in a Brownfield plan. In urban communities that have created an Obsolete Property Rehabilitation District, property owners may also receive an abatement of up to 100 per cent of real property taxes for a Brownfield site for up to 12 years.

In 2005, the state of New York offered tax credits to participants in the Brownfield Cleanup Program. The tax credits offset the costs of site preparation, property improvements, on-site groundwater cleanup costs, real property taxes, and environmental insurance premiums. The credits can be used for site remediation and also for environmental remediation insurance.

In 1999, Wisconsin's legislature adopted tax provisions to help local governments in cleaning up contaminated, tax-delinquent properties. In addition to tax incentives, direct capital attraction strategies are also needed to help remediation projects. For example, loans can make financial resources directly available to the borrower. Such policies may free up financing by assigning the decision levels to local governments and developing state-level insurance pools to protect investors.

1.10   FUTURE IN ENVIRONMENTAL POLICY AND REGULATIONS

This Module has provided general information on basic principles being used nationally and internationally to set regulations, and to develop criteria and permissible levels of contaminant concentrations, in an effort to protect the environment and human health. As developing countries join in the production and utilization of chemicals in the hopes of improving their living standards, they are facing very serious environmental challenges. Due to lack of regulations and/or implementation of policy, serious environmental consequences can result with negative impact on human health and the environment. There are lessons to be learned from developed countries where people have suffered from toxic effects of the chemicals. It has also become clear that once fertile lands are polluted, the damage is irreversible.

Although the responsibility for developing and implementing environmental regulation and policy mostly rest with a country's Ministry of the Environment, achieving the required results depends heavily on inter-sectoral collaboration. Each Ministry of Environment must develop goodwill, close links, and more coordinated actions with other relevant ministries, governmental institutions and non-governmental organizations. This toolkit is intended to assist in capacity building with respect to dealing with POP-contaminated sites. The Ministry of Environment or Environment Protection Agency should maintain an inventory of all contaminated sites. As the country advances, the environmental policy will need to be modified accordingly. Despite serious economic and social problems facing most developing countries, a pro-active policy to address POPs and other toxic chemicals is an investment in the future health of people and in the creation of a healthy and sustainable environment, providing people in developing countries a better quality of living environment over the long term.

MODULE 2

CONDUCTING A SITE INVESTIGATION

This module provides guidelines on investigating a site that is potentially contaminated with persistent organic pollutants through two distinct phases:

- the preliminary site investigation, which is made up of two stages, and confirms whether a site is contaminated or not
- the detailed site investigation, which delineates the extent of contamination

You will also find some helpful checklists for conducting site investigations along with a standard format for preparing a site investigation report. The two detailed case studies on site investigations in Lagos, Nigeria and Accra, Ghana may also be useful aids in preparing your report.

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2.1 INTRODUCTION

A site is generally considered contaminated by persistent organic pollutants (POPs) when one or more contaminant concentrations exceed the regulatory criteria. Site investigation, comprising preliminary site investigation (PSI) and detailed site investigation (DSI), provides valuable information on a site, including:

- the nature and location of contaminants with respect to the soil and groundwater table
- potential pathways for contaminant migration
- the location of nearby sensitive receptors
- the potential for direct human exposure to the contaminants

It is then possible to establish the relationship between the contaminants, exposure pathways and receptors using a conceptual model. Therefore, the accuracy of the information gathered and analyzed during the investigation is vitally important because it forms the basis for the risk assessment phase (see Module 3), for making decisions on the need for, and type of, remedial action and, eventually, for the design and implementation of the necessary actions (see Module 4).

In preparing this module, we have followed guidelines from various jurisdictions including the provincial governments of British Columbia and Alberta in Canada, the federal government of Canada and the Government of New Zealand. However, this module[1] is mainly based on guidelines from British Columbia, which document best practices that can be most easily adopted by most developing countries.

These guidelines will be useful for a variety of audiences including industry groups, planning and regulatory authorities, developers, lenders, property insurers and valuers, property owners, and interested members of the community.

During a site investigation, every item of information collected must be recorded properly on paper, along with photographs of the site and the surrounding area, with a radius of about 50-100 m (depending on the size of the site). Reporting is essential for each stage of the investigation (see Section 2.4) as site-specific information is invaluable to decision-makers in their efforts to protect the environment.

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[1] **Source of Information:**
Alberta Environment Site Assessment Guidelines (2008),
British Columbia Technical Guidance on Contaminated Sites (2009),
http://www.mfe.govt.nz/publications/ser/hazardous/contaminated-land-mgmt-guidelines-no5/html/page4.html
A Federal Approach to Contaminated Sites-Government of Canada (1999).

2.2 HOW TO CONDUCT A PRELIMINARY SITE INVESTIGATION

A preliminary site investigation is made up of two major stages:
- **Stage 1:** Collecting and compiling site information from available relevant and credible documents
- **Stage 2:** Establishing a conceptual site model and sampling the relevant environmental media for potential contaminants of concern (PCOCs)

PSI Stage 1

The objective of Stage 1 is to gather sufficient information to stimate the likelihood of POP contamination that may be present at a site. Sampling relevant environmental media and investigations of subsurface conditions are not required at this stage.

PSI Stage 1 includes the following activities:
- **Historical review:** review of a site's historical use and records to determine current and past activities or uses, accidents and spills, and practices and management relating to potential contamination at the site and at adjacent sites
- **Site visits:** one or more walk-through site visits to verify the information gathered during the literature review for indicators or presence of contamination
- **Interviews:** interviews with current or former owners, occupants, neighbours, managers, employees, and government officials who can, with reasonable attempts, be contacted about information on activities that may have caused contamination

It should be noted, however, that while the information that is required in PSI Stage 1 readily flows in developed countries. it is not always available or accessible in most developing countries. It is hoped that over time there will be a systemic and attitudinal change in the populace of developing countries. For now, site investigators will have to make do with the best information that they can collect.

Historical review

This activity should include the following actions:
- review historical and recent aerial photographs of the site and surrounding area
- interview people who are knowledgeable about the property's history including past and/or present owners or tenants, neighbours, etc.
- review existing studies including health impact studies, statistics, environmental impact studies, previous environmental audits, geotechnical reports, and subsurface information such as borehole logs, etc.
- gether site physiography including regional and site geograpyh, climate, topography, geology, surface water and groundwater, water supply, surface cover and vegetations
- consult emission inventory reports
- consult the site or property registry
- consult potentially POP-contaminated site inventories, if applicable
- examine prior land usage and granted permits (city archive)
- review any environmental incident reports including those on spillages and leakages

Site visits

This activity includes one or two walk-through site visits to visually inspect:
- buildings and property
- equipment
- land
- surface water
- biota for indicators
- presence of contamination

Interviews

Site investigators should interview stakeholders who can, with reasonable attempts, be contacted regarding information on activities that may have caused contamination. Such stakeholders may include:
- current or former owners
- occupants
- neighbours
- managers
- employees
- government officials

Reporting of PSI Stage 1

See section 2.4 for details.

PSI Stage 2

Stage 2 should be conducted only if Stage 1 indicates there is a likelihood of POP contamination at the site or if there is insufficient information to conclude that there is no potential for POP contamination. The objective of Stage 2 is to confirm the presence or absence of the suspected contaminants identified in Stage 1 and to obtain more information about them. To achieve this objective, site investigators must carry out the following activities:
- development of a conceptual site model
- development of a sampling plan
- sampling of relevant environmental media
- laboratory or field instrumental analysis of sampled and selected environmental media for substances that may cause or threaten to cause contamination

Developing a conceptual site model

A conceptual site model (CSM) is a system diagram that identifies contaminant *sources*, routes of exposure (*pathways*), and the *receptors* that are affected by contaminants moving along those pathways. The CSM, which should be developed at the very beginning of PSI Stage 2, identifies the zones of the site with different contamination characteristics (i.e., whether contaminants in the soil are likely to be at the surface or at deeper levels, distributed over an entire area or in localized "hot spots"). Exposure pathways and receptors should be

identified, where appropriate, for both current and future uses of the site. The CSM is based on a review of all available data gathered during Stage 1 , and should be continuously modified as more information becomes available during Stage 2 and the detailed site investigation.

Developing a sampling plan

A sampling plan must be developed to obtain more definitive information about the presence of contaminants in the hot spots identified in Stage 1. (Note that Stage 1 must be done as thoroughly as possible following the steps outlined above.). It is not necessary to create an exhaustive sampling plan that delineates the extent of the contamination at this point, as that will be the scope of the detailed site investigation. However, the environmental sampling plan must enable the general location and degree of contamination to be determined. The investigator must be able to explain the rationale behind the sampling plan needed to satisfy the objectives of the investigation. The sampling techniques (see below), field observation and records, laboratory testing methods (see below), field screening techniques and QA/QC (quality assurance and quality control) methods must be included in the sampling plan. Therefore, a good sampling plan should adequately identify the POPs (and other) contaminants that exist and their general distribution, which will then provide an indication of potential sources, pathways, and receptors of POPs.

The intensity of Stage 2 is determined by the complexity of past and present site use, the site size, the specific types of POPs, and potential mechanisms of contaminant transport Stage 1). The sampling points should ideally be located in a grid pattern to provide a good representation of the extent and nature of the contamination. Extra sampling points should be located at or near potential POPs sources, e.g., near underground or above-ground storage tanks. Stage 2 focuses on probable contaminated areas (suspected hot spots), and sampling generally is carried out based on a coarse grid with 25- to 50-m spacing between sampling locations (BCMOE, 2009).

The costs for analyzing POPs are very high, especially in developing countries. As a result, extensive analyses may be impossible in a PSI, in which case the investigator can adopt the hot spots approach. For further information, see Section 2.3 and Figure 2.1, along with the case studies from Nigeria and Ghana.

Sampling of relevant environmental media

The sampling program should include surface and subsurface soil sampling, and groundwater and surface water sampling. Subsurface soil samples are routinely collected through the excavation of test pits, the use of a hand auger and a portable drill, or by drilling boreholes. Groundwater samples are collected by installing monitoring wells at strategic borehole locations. See Section 2.5, *Tools and Resources*, for more detailed information on soil and groundwater sampling methodologies, as well as the environmental properties of the POPs of concerns. Additional sampling, including of sediment, plants or aquatic organisms, may be warranted under certain site-specific conditions.

Laboratory or field instrumental analysis

Sample analysis should address the range of possible contaminants identified in Stage 1. This analysis may become more refined as investigation activities proceed and the types of

contaminants to be analyzed are properly identified or the areas of potential environmental concern discarded. On-site methods should be explored as they allow samples to be screened for a variety of suspect contaminants in a cost- and time-effective manner. Samples with the highest contaminant concentration identified by the screening method should then be submitted to a laboratory for detailed analysis. In addition, on-site methods can be used to determine the need and best location for further drilling, if required.

Reporting of PSI Stage 2

See section 2.4 for details.

How to use the PSI Checklist

The PSI checklist in Section 2.5, *Tools and Resources*, highlights many—but not necessarily all — important features of a good preliminary site investigation. This list should be considered as guidance only, and environmental consultants should also consider site-specific factors and the usefulness of the information provided in the PSI.

Items 1 to 14 and 25 to 29 of the checklist should be considered for Stage 1 while items 15 to 24 should be used in Stage 2. This checklist does not replace country-specific Environmental Management Acts or other regulations. It does not list all provisions relating to a PSI. If there are differences or omissions in this document, country-specific Acts and regulations apply.

The investigators, government agencies and others who are conducting PSIs should follow the steps listed in this module along with reviewing the checklist before conducting a site investigation. The checklist should be viewed as a dynamic document that needs to be continually updated with site-specific information.

2.3   HOW TO CONDUCT A DETAILED SITE INVESTIGATION

A detailed site investigation is required on sites where a preliminary site investigation has confirmed contamination. A DSI is used to determine the nature and extent of the contamination for all media of concern (e.g., soil, groundwater) including specific areas, depths, degree, and migration potential. Sampling locations are selected based on the results of the PSI and the physical conditions at the site. This phase of sampling may require multiple sampling events, as there is usually a lag time of around a week for sample results to be returned from analytical laboratories.

The information gained in a DSI is then used for the risk assessment (as described in Module 3) and the development of a remediation plan (see Module 4), if required. A DSI is designed to provide the information needed to assess risks to human health associated with exposure to contaminated soil, groundwater and surface water. A DSI should answer the following two questions:
- Does the presence of contaminants pose an unacceptable risk to the receptors under consideration?
- If so, what is the acceptable risk-based concentration limit?

The scope of a DSI includes:
- identifying the media to be sampled (soil, sediment, groundwater, surface water, soil vapour, air)
- identifying the type, concentration and distribution of chemicals present
- characterizing a site's geology, hydrogeology and physical setting in sufficient detail so that the contaminant data can be properly interpreted
- acquiring data for assessing remedial alternatives, if necessary
- providing data for assessing exposure pathways and risk analysis

How to Conduct a DSI

Here are the six main steps to be followed when conducting a DSI.

Step 1: Develop a detailed work plan

A detailed work plan should be designed to guide the collection of information that will refine the site characterization determined in the PSI, and to define the extent and concentration of any contaminants. The field activities described in the work plan should include:
- sampling locations
- sampling media and investigation tools
- sampling rationale and design
- chemical analyses
- quality assurance and quality control

Step 2: Prepare for site investigation

These preparations should include preparing a Health and Safety Plan and an Emergency Plan, which should address the following items:
- identification of potential chemical hazards
- identification of potential physical hazards
- hazard mitigation through controls and personal protective equipment
- field procedures to be followed to address potential hazards
- underground utilities

Step 3: Update the conceptual site model

As mentioned earlier, the CSM must be continually updated and refined as new information is obtained during both the PSI and the DSI.

Step 4: Conduct sampling and analysis

A sufficient number of sampling sites must be established to clearly delineate each area of potential environmental concern (APEC). This means that some sampling will occur in areas where contamination was not previously suspected.

Sampling designs

To establish the contaminant distribution at a site, small quantities of soil are collected and submitted for analysis. There is always some uncertainty about the representativeness of the samples to actual site conditions due to a number of factors, including:

- cross-contamination
- variations in local conditions, which can affect the vertical and lateral distribution of contaminants

Users should select the sampling approach that seems most suitable for the site-specific conditions.

The four types of sampling approaches (SW-846-USEPA), which are illustrated in Figure 2.1, are as follows:

- *Random:* performed on sites where background information is not available and no visible signs of contamination are present.
- *Systematic:* involves collecting samples at predetermined, regular intervals within a grid pattern. Systematic sampling is the most common strategy and makes no assumptions about distribution or movement of analytes.
- *Judgemental:* carried out when specific information is known about the configuration of the release, movement and distribution with time, and distance (fate and transport).
- *Combinations:* frequently the *judgemental* approach is combined with the *systematic* or *random* to take advantage of the different approaches.

See Section 2.5, *Tools and Resources*, for more detailed information on soil sampling methodologies.

Systematic

Random

Judgemental

Combination
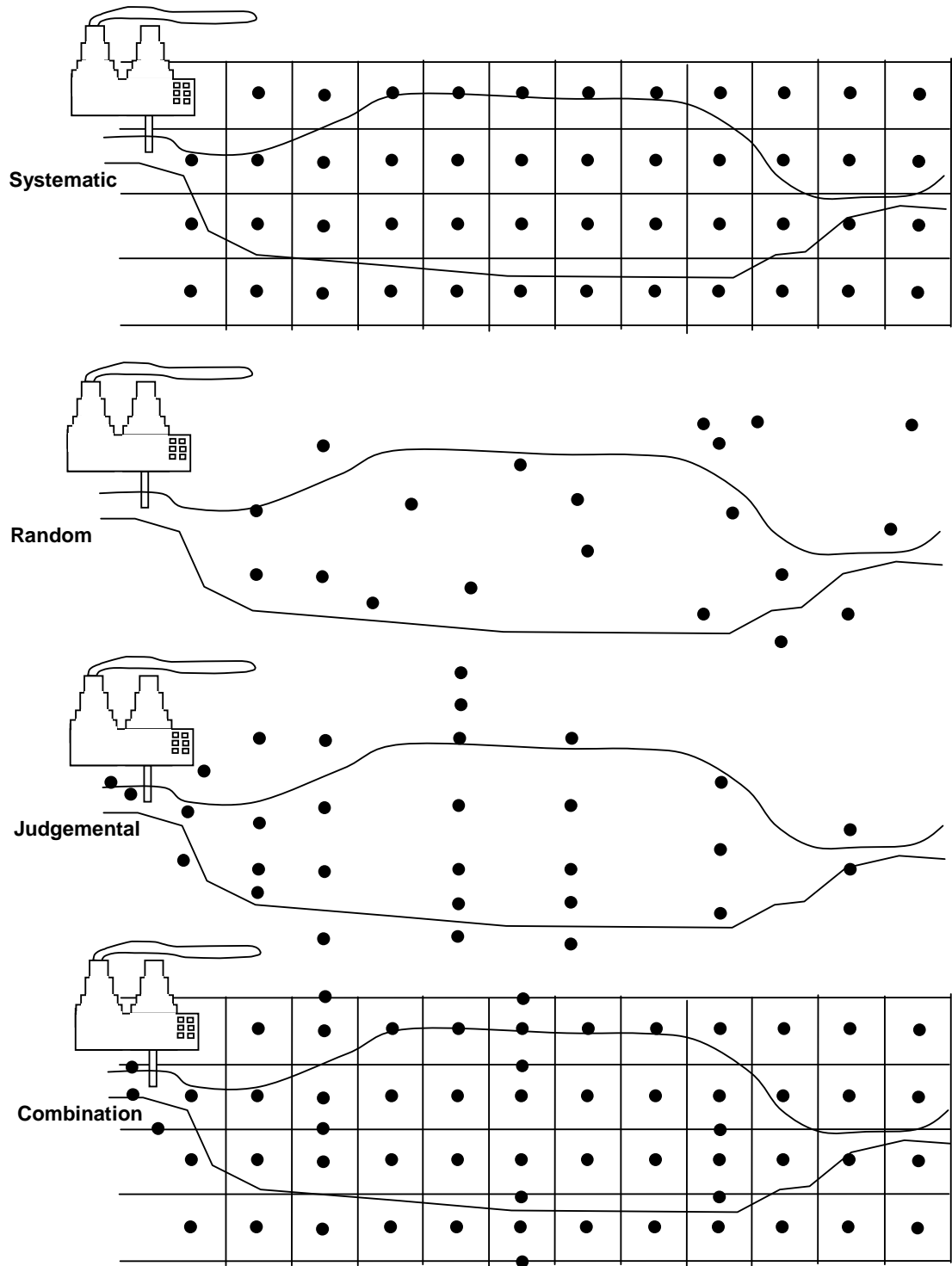
Figure 2.1
Examples of sampling types (modified from Keith, 1983)

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Minimum number of test samples

As stated previously, the intensity of a site investigation is determined by the complexity of past and present site uses, size of the site, types of POPs, geological and hydrogeological situation, soil types, and potential mechanisms of contaminant transport. A DSI defines the lateral and vertical extent, magnitude, and variability of contamination, and estimates the contaminant distribution depending on the site situation. Table 2.1 provides the recommended minimum number of test samples for in-situ 200m^3 or less soil stockpile.

Table 2.1
Minimum number of test samples for in-situ 200m^3 or less *

Soil volume, m^3	No. of samples
25 or < 25	3
50	3
75	4
100	5
125	7
150	8
175	9
200	10
>200	1:25

* BCMOE Contaminated Site Guidances

Laboratory accreditation

Laboratories to be used for chemical analysis of soil, groundwater and sediment samples must be accredited by the appropriate regulatory agency.

Step 5: Interpret and evaluate data

The interpretation of the laboratory data includes i) a comparison between the data quality objectives and the findings presented in the field program, ii) an evaluation of the quality assurance/quality control data with the data presented, and iii) an extrapolation of the information presented to a form that will truly represent site conditions. The gathered data must be representative of the contaminated site that is under investigation.

When a contaminated site has been identified and the testing results have provided information on the nature and magnitude of contamination, the criteria listed in Module 3 can be used for the purpose of evaluating:
- the degree of contamination at the site
- if further site investigations are required

Reporting of DSI

See section 2.4 for details.

How to use the DSI Checklists

Section 2.5, *Tools and Resources*, contains a DSI checklist that outlines the activities and steps described in this section. This checklist covers the following areas:
- site history and description
- the data to be collected
- statistical analysis and interpretation

It also details materials and activities including:
- required materials and equipments
- personal protective equipments
- drilling and installation of monitoring wells
- soil, and surface and groundwater sampling activities
- geophysical investigations, topographic survey and health and safety measures
- environmental site monitoring in the field

Tools and Resources also contains a second checklist, which details a data entry format that will help consultants, engineers and regulatory agents to understand the field situation at a glance and to comply with relevant safety, health and environmental issues.

2.4   HOW TO DEVELOP A SITE INVESTIGATION REPORT

This section provides some guidance on how to create a site investigation report. Users can modify the report outline according to their site-specific needs.

A site investigation report is typically made up of the following main components:
a) **Title page**: A title clearly identifying it as a Stage 1 PSI, Stage 2 PSI or DSI report. Site address/location, consulting company, client and date of report
b) **List of Acronyms**
c) **Executive Summary**: Synopsis of the report, summary of work undertaken and key findings/conclusions
d) **Introduction**: Describe the purpose, objectives, scope of this work
e) **Body of report**: See details below
f) **Conclusions**: Conclude the contamination potential/level, see details below
g) **Recommendations**: Recommend further work along with timelines to address the potential/exceedance on-site and off-site
h) **Limitations**: Legal clauses, such as parties authorized to use information contained in the report; provide information of limitations on liability and disclosure
i) **References and Supporting Document**

The structure of the report is usually based on Stages 1 and 2 of the PSI, followed by the DSI.

SI Stage 1

The objectives of a PSI Stage 1 are to determine potential contamination.

The body of the report should include the following items:

Site location
- general description
- municipality
- civic address
- PIN/PID
- legal description
- geodetic coordinates for centre of site

Site physiography
- general area description
- general site description
- regional geology
- site geology
- topography
- surface cover
- vegetation
- surface water
- groundwater
- water supply
- climate

Site usage and activities, adjacent areas usage and activities
- aerial photographs
- city directories
- title search
- fire insurance maps
- site records
- site registry
- interviews

Site reconnaissance and potential contamination identified
This section should include photographs and a detailed record of what was observed during the site visit.

Conclusion
The conclusion should identify potential contamination:
- a) potential source of contamination
- b) potential contaminants of concern
- c) areas of potential environmental concern (potential lateral extent, vertical extent, media)

PSI Stage 2:

The objectives of a Stage 2 PSI are to determine if contamination is present.

The body of the report should include the following items:

Site synopsis
A site synopsis should be included if the Stage 2 report is being prepared and submitted separately from any Stage 1 report.

Investigation plan
- rationale for all investigation locations (e.g., test pit, borehole, monitoring well) with respect to area of potential environmental concern
- rationale for all individual samples collected
- rationale for all analytes with respect to potential contaminants of concern

Investigation methodology
- details of equipment used
- details of sampling protocols
- general statement of analytical technique
- quality assurance protocols

Regulatory framework
- regulations used and rationale (CSR, HWR)
- for CSR generic soil, describe applicable land use and rationale
- for CSR matrix soil, describe all site specific factors, their applicability, and the rationale
- for CSR generic water, describe all water uses, their applicability, and the rationale, and if groundwater or surface water

Investigation results
- geology encountered
- hydrogeology encountered
- field observations of contamination
- analytical results
- quality assurance (QA) results

Although logs will have details of the first three items above, they should also be summarized in tables Analytical records and drawing showing exceedances should be included. Reference point data (RPD and lab quality control (QC) should be discussed.

Conclusion
The conclusion should identify contamination and potential contamination including:
a) source of contamination
b) contaminants of concern (i.e., types of POPs)
c) areas of environmental concern (potential lateral extent, vertical extent, media)
d) recommendations for action

DSI Reporting

The objectives of a DSI are to determine the extent and degree to which contamination is present. The report components are generally similar to those of a PSI Stage 2 report, but with a few key differences:

- A DSI should include cross-sections of the contaminant profiles.
- A DSI should include volume calculations of contamination.
- There should be a greater emphasis on hydrogeology, including preferential pathways.

Conclusion

The conclusion should identify contamination and potential contamination including:

a) extent and degree of contamination
b) on-site and off-site migrations
c) media and pathways (i.e., air, dust, water, soil, sediment, etc.)
d) recommendations for action

2.5 TOOLS AND RESOURCES

Preliminary Site Investigation Checklist

Section 1	Checklist Preliminary Site Investigation Stage 1 (Items 1–14 and 25–29)	Status Y/N
SUMMARY *Analyses*	1. Does the investigator: a) identify who the major participants are in the investigation; b) state his/her qualifications; c) identify if the study is a first or second stage preliminary site investigation; d) indicate whether the investigation proceeded in stages; e) provide the objectives, methods and procedures that were used in each stage; f) describe the relationship of the two stages; and g) summarize the results, including an evaluation of data that clearly shows the classification, general location and degree of contamination in soil, groundwater, sediments, and surface water?	
	2. Does the summary: a) identify what contaminants the analysis program focused on; and b) indicate how reliable the sampling methodology and laboratory analysis was?	
OBJECTIVES *Goals*	3. Are the goals of the investigation: a) clearly stated; b) in compliance with the scope of work agreed upon with the client; and c) consistent with Ministry of Environment goals and objectives?	
SITE HISTORY & DESCRIPTION *Description of the site*	4. Has the investigator provided: a) a legal description of the property; b) the civic address of the property; c) results from a title search; d) a legal plan from the Land Titles Office; e) information from the ministry on the presence of contaminated sites within 500 metres of the property; f) information from the ministry groundwater section (more relevant for rural properties); g) municipal service plans (if relevant); h) a synopsis of building plans from municipal building inspection departments; i) a municipal zoning plan; j) photos of subject property and adjoining properties; and k) the dates when site visits were conducted?	

Historical review	5. Has the investigator:
	a) reviewed the following information;
	    • site plans and diagrams.
	    • aerial photographs.
	    • Site Registry records. (mandatory, index results & detail reports to be included)
	    • city directories
	    • property titles
	    • fire insurance records
	    • information provided by current site owners and those knowledgeable about the site
	    • previous environmental or geotechnical reports relevant to the site.
	b) searched the BC Directory for history of occupiers at subject's civic address;
	c) done additional title searches if necessary to determine site ownership history;
	d) described the historical activities likely to have been present on site;
	e) listed type of contaminants likely to have been associated with each site activity (past/present);
	f) outlined the mechanism of contamination (how, who, why, source, pathways, receptors); and
	g) speculated on age of contamination?	

Maps	6. Has the investigator: a) *provided a site map, including land use, relevant buildings found on site, dimensions in metres and area of property in hectares;* b) *reviewed aerial photographs of the site and adjacent environs taken prior to and after development, in preparation of historic uses* c) *included natural features such as lakes, rivers, streams found at least partially within the boundaries of the property;* d) *included constructed features such as underground storage tanks, lagoons, ditches, sumps within buildings, and waste storage areas;* e) *provided an area topographic map of 1:20 000 or larger*?	
Surface conditions	7. Has the investigator provided: a) information related to topography (e.g., how it relates to possible groundwater flow and direction of surface runoff); b) an estimation of the percentage of the site presently occupied by buildings and paved areas; c) an estimation of the percentage of the site occupied by buildings and paved areas in past industrial/commercial configurations; d) a general description of adjacent property, water resources; e) the distance to surface water, drinking water supply sensitive environments; f) a discussion of the flood potential of the site?	
Groundwater	8. Has: a) an attempt been made to determine if and where septic systems exist on site, using local government files, etc.; b) an assessment of groundwater vulnerability been provided through information about site soil conditions including texture, structure, thickness, and the content of organic matter and clay minerals; c) a general interpretation of groundwater flow and depth been provided by a qualified hydrogeologist; and d) the assumption behind interpretations of groundwater depth and movement been provided?	

Wells	9. If monitoring wells have been installed near the disposal areas previous to this investigation: a) have the monitoring results been reviewed; b) have data been included that indicate why and when a monitoring well was installed and by whom; and c) has any previous geotechnical investigative work been identified and reviewed?	
Soil types and soil depths	10. Has the investigator: a) provided soil survey information; b) contacted soil survey personnel, or soil scientists, if no soil survey information is available; c) indicated whether there is visible signs or sources of pollutants on the surface of the soil?	
Climatic conditions Industrial sites Basic preliminary assumptions about contaminants and migration mechanisms Basic preliminary information about liability	11. Has the investigator provided: a) annual precipitation records; b) along with a description of seasonal variations in precipitation; and c) estimates of infiltration rates? 12. For industrial/commercial sites currently operating: a) has the investigator identified manufacturing processes, raw materials, chemicals or fuels used; b) has the investigator identified the potential waste streams; c) has each waste stream's chemical characteristics, volume, and methods of treatment and disposal been determined; and d) has the presence of electrical transformers or capacitors been determined? 13. Has the investigator: a) provided approximate concentrations and general locations of contaminants (random or non-random, large area extent or confined, near surface or at depth); b) discussed reactivity (soluble or non-soluble, volatile or non-volatile)and the toxicity rating (human & ecological) of the potential contaminants of concern; c) listed activities in neighbouring properties to a distance of at least 300 metres from the site under investigation; d) provided evidence that migration has occurred (reliable or unreliable); and e) examined surface waters (including ditches) for signs of contamination? 14. Does the investigator: a) provide adequate information about any court or administrative actions, ministry orders, Federal charges under the *Fisheries Act*, etc.?	

SECTION 2	Preliminary site investigation Stage 2 may include 15–24	Status Y/N
DATA *Goals of the study*	15. Has the investigator discussed the following about the potential contaminants of concern: a) what are the goals of the preliminary site investigation; and b) will analysis of the populations identified in the study lead to achieving these goals?	
Populations	16. Does the sampling plan and data: a) adequately identify the contaminants that exist and represent their general distribution; b) establish the physical and chemical controls on contaminant distribution?	
Plans	17. Has the investigator: a) explained the rationale behind the sampling plan; b) provided a sampling plan that reflects the potential sources, pathways, and receptors of contaminants; c) over-sampled to compensate invalidated results (broken bags, lost labels, etc.); d) avoided collecting composite samples; e) provided a rationale for using composites or a combination of composite and discrete samples, f) detailed the procedures used to collect, record; confirm and verify the database; g) provided an adequate location for each sample (e.g., has the sample grid been tied into UTM co-ordinates); h) has the investigator attempted to determine the background soil conditions for the parameters being investigated; and i) does the investigator provide a rationale for choosing the area used to represent ambient conditions?	
	18. If previous studies have been used: a) have the data been summarized and presented in the report; b) have the data been used to add to the density of sampling locations; c) has the source of additional data been identified and its use justified; and d) has the investigator given reasons for including or excluding data from previous studies?	
Protocols	19. Have field sampling procedures been carried out according to: a) ministry protocols where available; and b) if modified, presented justification for such modifications?	
	20. Has the investigator: a) included the original quality assurance plan; b) run a complete check of all data against original records; c) provided documentation of the reliability of any data that is significant to the study's conclusions; d) shown that the analytical methods used for all samples conform with methods accepted by ministry recommendations; e) used paired analyses of duplicate samples (where samples are collected separately in the same immediate area); f) used paired analyses of split samples of the same material especially where suspected contaminant levels are believed to be at their highest concentrations; g) discussed the possible reasons for differences between splits and field sample duplicates; h) have recommended ministry lab services QA/QC protocols been followed; and i) documented any corrective action taken if QA/QC reveals significant bias or high imprecision?	

EXPLORATORY DATA ANALYSES	21.	For univariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; c) made use of graphical representations of the data, such as histograms, or probability plots; d) used summary statistics that describe the centre, location, spread, and shape of the univariate distribution; and e) used logarithmic scaling, if the data are skewed, to make graphical presentations more informative?	
	22.	For bivariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; and c) used scatter plots that display the relationship between pairs of variables and linear and rank correlation coefficients that summarize the strength of the relationship?	
Outliers	23.	For all distributions, has the investigator: a) used rank correlation as an alternative to linear correlation to reduce sensitivity to outliers when summarizing the relationship of two variables; b) used probability plots, scatter plots and data postings to identify outliers; c) determined whether any outliers require that any critical assumptions need to be modified; d) determined the reasons for the existence of the outlier; e) documented the reasons for and provided all relevant information about any outlier value that has been discarded; and f) taken a new sample at a random location within one metre of a discarded outlier sample?	
STATISTICAL ANALYSIS AND INTERPRETATION *Assumptions*	24.	Has the investigator: a) described the statistical tools and procedures used to analyze and interpret the data along with their underlying assumptions; b) included calculations and assumptions for population standard deviations estimated for the purposes of a confidence interval calculation; c) provided a rationale for the method used to deal with non-detectable data; d) used a nonparametric alternative as a way of checking the sensitivity of the conclusion to the distribution assumption; and e) included a statement about the uncertainty of all estimated or predicted values?	
CONCLUSIONS AND RECOMMENDATIONS *Conclusions*	25.	Has the investigator: a) identified high risk concerns; b) provided clear and unambiguous conclusions with specific references to the analysis and interpretations that support them; and c) discussed how each conclusion is affected by any underlying assumptions, by the accuracy and precision of the available sample data and by the uncertainty in estimated or predicted values?	
Recommendations	26.	Has the investigator: a) provided clear and unambiguous recommendations; b) informed the client of any other issues of potential concern outside of the original goals of the study; and c) provided rationale with any recommendations for further investigation?	
REFERENCES *Complete Information*	27.	Has the investigator referenced: a) all data sources, previous studies and other sources (including interviews) that contributed information to the study; and b) any technical literature that provides additional detail on procedures used in the study?	

| APPENDICES *QA/QC* Documentation | 28. | Has the investigator provided:
a) analytical laboratory results, either in printed form or on a diskette (Excel preferred) (mandatory requirement);
b) Laboratory QA/QC procedures, sampling protocol and the results of check analyses (mandatory requirement);
c) drill logs and test pit logs (mandatory requirement); and
d) a site map showing sampling locations? (mandatory requirement – may be included in the main report) | |
| | 29. | Has the investigator included:
a) details of statistical computations omitted from the main body of the report; and
b) if used, the name and version of the computer software utilized for the data base compilation and the statistical analysis, or a brief description and a reference for any other non-commercial software used in the study? | |

Preliminary Site Investigation Summary

Using the information from the preceding checklist, please provide a summary containing the following information:
- investigation work quality and thoroughness
- the need for additional investigation
- the need for a site visit by ministry staff
- levels of certainty
- compliance with the ministry's Provincial legislation (if available), regulations and policy, criteria (if applicable) and guidelines, and
- sign-off sheets appropriately signed.

Statement of objectives

Description of investigation

- including what parameters were tested and why

Rationale for sampling program

- sampling locations and parameters
- sampling rationale

Data presentation

- chemistry data
- hydrogeologic data
- other

Data interpretation and evaluation

- areas of environmental concern
- areas not of environmental concern
- contaminant migration
- level of confidence

Recommendations

- need for further investigation
- assessment of recommendations

Detailed Site Investigation Checklist 1

A.) REQUIRED MATERIALS			
Personal Protection Equipment	OK	NA	Units
• Chemical protective clothing (e.g. disposable Tyvek suit) for high risk			
• Fall protection equipment			
• Reflecting vest and/or other visibility reflecting accessories			
• Face masks			
• Full face mask respirator and mask filters (against organic vapours and toxic particles)			
• Safety helmet			
• Shatterproof safety glasses			
• Hearing protection			
• Work gloves and single-use nitrile gloves			
• Safety boots			
• Overshoes/Overboots			
Collective protection equipment	OK	NA	Units
• First aid kit			
• Emergency showers			
• Eye wash cleaning water			
• Autonomous oxygen supply			
• Fire extinguisher			
• Detection devices (for fumes, gases, etc.)			
• Absorbent paper			
Drilling machine	OK	NA	Units
• Drill pipes			
• Drill crowns			
• PVC pipe			
• Slotted pipe			
• Stopper			
• Pipe cap			
• Gravel			
• Cement			
• Bentonite			
• Cover			
Equipment for soil-gas, hydraulic conductivity and sampling activities	OK	NA	Units
• Hand auger equipment			
• PID (Photoionization detector)			
• Teflon tube			
• Freezing bags			
• Explosimeter			
• pH meter			
• Conductivity and temperature meter			
• Redox meter			
• Dissolved oxygen meter I			
• Interphase probe			
• Bailers (minibailers)			
• Pumps (minipurgers)			
• Cool boxes			
• Soil sample bags			
• Water sample bottles (containers)			
• Adhesive labels for sample bags			
Geophysical works	OK	NA	Units
• Geophysical gear			
• Laptop and its charger			

	OK	NA	Units
• Data registry and storage system			
• Extension cord			
• Adapters			
• Wire coils			
• Network cable			
• Probe or small measurement device			
• Electric winch			
• Junction cable between probe and data registry/storage equipment			
• Voltmeter to check connections			
Other materials	**OK**	**NA**	**Units**
• Toolbox			
• Geological hammer			
• Allen wrench			
• Screwdrivers			
• Mallet			
• Pliers			
• Compass/GPS (Geographical Positioning System)			
• Spray or paint for marking			
• Insulating tape			
• Packaging tape			
• Tape measure			
• Photo camera			
• Notebook & pen			
• Edding			
• Cutter			
• Scissors			
• Penknife			
• String			
• Lantern			

	OK	NA
B.) HEALTH AND SAFETY MEASURES		
• Is there an approved Health and Safety Plan?		
• Has every member of the team been instructed about the Health and Safety Plan?		
• Have affected people/organizations been warned about the works?		
• Can all the Health and Safety Plan requirements be fulfilled?		
C.) ENVIRONMENTAL SITE ASSESSMENT		
C.1.) Soil gas analysis	**OK**	**NA**
• Performance of a utility survey		
• Determination of distribution of soil gas investigation points		
• Determination of sampling depth		
• Pre-drilling		
• Drilling of boreholes		
• Soil gas sample collection		
• Field analysis of soil gas samples		
• Laboratory analysis of soil gas samples		
C.2.) Application of geophysical methods	**OK**	**NA**
• Design for establishing the position of soil profiles to be analyzed		
• Determination of direction and length of soil profiles to be analyzed		
• Determination of number of soil profiles to be analyzed		
• Determination of separation between soil profiles to be analyzed		
• Determination of separation between measurement points		
• Taking measurements		
C.3.) Drilling of soil borings	**OK**	**NA**
• Location of soil borings		
• Design of soil borings distribution in the study area		
• Sign exact sampling points with painting/spray		
• Execution of soil borings (for each drilling location)		
• Performance of utility survey		
• Drilling of localization soil borings (3-4 m depth)		
• Drilling of investigation soil borings (more than 4-5 m depth)		
• Filling of each hole with grout to ground surface after conclusion of each soil boring		
• Collection of the following information during drilling works		
• Name or identification number of soil boring		
• Start and end date of works		
• Observed lithology		
• Soil appearance and colour		
• Presence of humidity		
• Water levels and non-aqueous phase liquid levels		
• Drilling company		
• Drilling typology		
• Boring depth		
• Drilling device diameter		
• Collected samples, with relative sampling depth and identification code		
• Stratigraphy, with possible visual exam notes		
• Taking photographs of samples and sample locations		

	OK	NA
C.4.) Installation of monitoring wells		
• Completion of strategic investigation soil borings as monitoring wells installing piezometers		
• Well development and purging until the water runs clear and physicochemical parameters are stable		
• Measurement of the following parameters prior, during and after well development		
• Static water level		
• Groundwater presence and level		
• Water colour		
• Turbidity		
• Odour		
• pH		
• Temperature		
• Specific conductance		
• Presence of non-aqueous phase liquid (NAPL)		
• Recording of data related to well installation activities, specifying:		
− Piezometer identification number		
− Measurement data		
− Piezometer depth		
− Piezometer location coordinates		
− Supervision of monitoring well installations by specialists		
C.5.) Topographic survey	**OK**	**NA**
• Measurement of X,Y,Z coordinates of each soil borehole, groundwater monitoring well and trial pit by means of a GPS		
C.6.) Hydraulic conductivity tests	**OK**	**NA**
• Performance of slug tests, either adding or removing a measured quantity of water from monitoring wells		
• Rapid water-level measurements at regular time intervals		
C.7.) Sampling activities	**OK**	**NA**
Soil sampling:		
• Extraction of soil core samples and placement in core boxes		
• Checking for the presence of any visual of olfactory evidence of contamination during drilling operation		
• Use of PID (Photoionization Detector) for rapid field sample analysis		
• Correct classification of soil samples taking into account parameters as soil type, colour, grain size distribution, textural changes, etc		
• Selection of representative samples		
• Soil sample preparation and placement into containers		
• Labelling of soil sample containers		
• Storage of soil sample containers at low temperatures (4ºC) and in the dark		
• Sending of soil sample containers in refrigerated or thermo-insulated boxes to the laboratory in 24-48 hours		
• Completion of Chain of Custody including for each sample the same information reported on its label		
• Taking photographs at sampling locations and of soil samples		
Groundwater sampling:		
• Collection of groundwater samples from monitoring wells after well development		
• Collection of water samples directly into appropriate containers		
• Labelling of water sample containers		
• Storage of water samples at low temperatures (4ºC) and in the dark		
• Sending of water samples to the laboratory in refrigerated or thermo-insulated boxes in 24-48 hours		
• Taking photographs at sampling locations and of water samples		

D.) ENVIRONMENTAL SITE MONITORING IN THE FIELD		
Groundwater contamination control through monitoring wells:	**OK**	**NA**
• Design of a strategic monitoring network: determination of optimal location and number of piezometers		
• Design of a monitoring program, including:		
− Frequency of groundwater level measurements		
− Frequency of groundwater sample collection		
− Water sample analysis types		

Detailed Site Investigation Checklist 2

Section	Checklist	Status Yes/No (Y/N)
SUMMARY *Important information*	1. Does the investigator: a) identify who the major participants are in the investigation; b) provide important facts and study results at the beginning of the report; c) provide a clear understanding of the data contained within the body of the report; and d) discuss the results of any preliminary site investigations?	
Sampling information	2. Does the summary: a) state how representative the sampling pattern and analysis is of property soil conditions; b) specify the probabilities of false positive and false negative answers; c) identify what the chemical analysis program focused on; and d) indicate how reliable the sampling methodology and laboratory analysis was?	
OBJECTIVES *Goals*	3. Are the goals of the investigation: a) clearly stated; b) in compliance with the scope of work agreed upon with the client; and c) consistent with ministry goals and objectives?	
SITE HISTORY & DESCRIPTION *Description of the site*	4. Has the investigator: a) specified the dates when site visits were conducted; . b) provided a site map, including land use, relevant buildings found on site, dimensions in metres and area of the property in hectares; c) included natural features such as lakes, rivers, streams found at least partially within the boundaries of the property; d) included constructed features such as, underground storage tanks, lagoons, ditches, sumps within buildings, and waste storage areas; e) provided a reasonable substitute if no site map is available; f) provided an area topographic map of 1: 20 000 or larger; and g) included a scaled aerial photograph of the site and adjacent environs?	
Climatic conditions	5. For DSIs are: a) annual precipitation records provided; b) along with a description of seasonal variations in precipitation; and c) estimates of infiltration rates provided?	
Groundwater	6. Has: a) the depth to groundwater from the ground surface and the depth and thickness of multiple aquifers been calculated; b) seasonal groundwater fluctuation been documented; c) the lithology and vertical permeability of the unsaturated zone been described; and d) the stratigraphy, structure, geometry, porosity, hydraulic conductivity, storage properties, transmissivity, and groundwater flow direction of the saturated zone been described?	
Wells	7. If monitoring wells have been installed near the disposal areas previous to this investigation, a) have the monitoring results been reviewed; b) have data been included that indicate why and when a monitoring well was installed and by whom; and c) has any previous geotechnical investigative work been identified and reviewed?	

Soil types and soil depths	8.	Has the investigator: a) provided soil survey information at a scale of 1:20 000 or larger; b) contacted soil survey personnel, or local soil scientists; c) provided an on-site map and appropriate cross-sections showing soil types, soil depth and other soil parameters that may be related to location and extent of contaminants; and d) shown the relationship between groundwater and soil in the cross-sections?
Basic preliminary information about liability	9.	Does the investigator: a) provide adequate information about any court or administrative actions, ministry orders, Federal charges under the *Fisheries Act* etc., orders; and b) surmise whether there will be any potential litigation in this case?
DATA *Goals of the study*	10.	Has the investigator discussed the following about the goals of the study: a) what are the goals of the detailed site investigation; b) will analysis of the populations identified in the study lead to achieving these goals; and c) are the goals extensive enough to identify the Area(s) of Environmental Concern (AEC)?
Populations	11.	For detailed site investigations has the investigator: a) used historical and other preliminary site investigation information to help delineate separate populations; b) attempted to identify how many contaminant distributions there are; and c) attempted to identify background levels in the surrounding area for contaminants that occur naturally or that may have been deposited by non-point sources?
Plans	12.	For detailed site investigations: a) does the investigator explain the rationale behind the sampling plan; b) does the sampling plan reflect the potential sources, pathways, and receptors of contaminants; c) does the plan reduce the potential of type I and type II errors; d) has the investigator over-sampled to compensate for invalidated results (broken bags, lost labels, etc.); e) has the investigator avoided collecting composite samples for preliminary site investigations; f) has the investigator provided a rationale for using composites or a combination of composite and discrete samples; g) has the investigator detailed the procedures used to collect, record, confirm and verify the database; h) does the investigator provide an adequate location of each sample (e.g., has the sample grid been tied into UTM co-ordinates); i) has the investigator determined the background soil conditions for the parameters being investigated; and j) does the investigator provide a rationale for choosing the area used to represent ambient conditions?
	13.	If previous studies have been used in the detailed site investigation: a) have the data been summarized and presented in the report; b) have the data been used to add to the density of sampling locations; c) has the source of additional data been identified and its use justified; and d) has the investigator given reasons for including or excluding data from previous studies?

	14. Has the investigator: a) used a regular grid with a randomly located origin to estimate contaminant distribution in non-areas of environmental concern (non-AECs); b) collected the number of samples needed to conform with the level of confidence require to establish contaminant levels in non-AECs; and c) used the coefficient of variation to determine if non-AECs have been unaffected by local AECs?	
	15. For the sampling plan has the investigator: a) oriented the sample grid in the direction (if known) of flow of the pollutant, which may relate to site topography or wind direction; b) selected random samples, locations and/or starting points using procedures based on uniform random numbers; and c) included a random number table?	
	16. For the detailed site investigation of stockpiles has the investigator: a) designed a sampling program that ensures a fair representation of the contaminant concentrations in the entire pile; b) based the stockpile classification on at least five separate analyses; and c) determined if the material within the pile is sufficiently homogenous to warrant classifying the entire under a single classification?	
	17. For investigations of groundwater: a) has the investigator used any groundwater data available from preliminary site investigations; b) have at least 3 monitoring wells been used with at least one located up-gradient of groundwater flow; .. c) have samples been collected at least 24 hours after the development of a well; d) have groundwater samples been collected after wells have been purged; and e) has integrity testing of underground storage tanks near sensitive receptors such as potable water supplies been carried out?	
Protocol	18. Has the investigator: a) included the original quality assurance plan; b) run a complete check of all data against original records; c) provided documentation of reliability of any data that is significant to the study's conclusions; d) shown that that no systematic bias has been used during the sampling procedure, including collection, preparation and analysis; e) shown that the analytical methods used for all samples are acceptable to the ministry; f) used control charts to monitor and control the accuracy and precision of the analyses for large studies with more than 100 samples; g) used a t-test to determine whether the average of repeat analyses is significantly different from the established reference value; h) used paired analyses of duplicates of the same material especially where suspected contaminant levels are believed to be at their highest concentrations; i) shown that paired analyses of sample material split in the field shows a rank and linear correlation of 0.95 or greater for metallic and inorganic contaminants, and 0.90 or greater for organic contaminants; j) followed recommended ministry lab services QA/QC protocols; and k) documented any corrective action taken if QA/QC reveals significant bias or high imprecision?	

	19.	For AECs: a) has the investigator ensured that the spacing between samples is smaller than the range of correlation; and b) has the investigator used multi-stage sampling plans to detect and identify the extent of hot spots, including fine grids and step-outs?	
EXPLORATORY DATA ANALYSES *Non-parametric method*	20.	For detailed site investigations, has the investigator: a) made all distribution assumptions explicit in the report; b) used non-parametric methods to show data that is not normally distributed; c) used percentile-based statistics, such as quartiles and the median, to supplement the more traditional mean and standard deviation; and d) used box plots as an alternative to histograms especially when comparing two or more groups of data?	
Univariate descriptions	21.	For univariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; c) made use of graphical representations of the data, such as histograms, or probability plots; d) used summary statistics that describe the centre, location, spread, and shape of the univariate distribution; and e) used logarithmic scaling, if the data are skewed, to make graphical presentations more informative?	
Bivariate Descriptions	22.	For bivariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; and c) used scatter plots that display the relationship between pairs of variables and linear and rank correlation coefficients that summarize the strength of the relationship?	
Spatial Description	23.	Has the investigator used: a) contour maps and cross-sections to show spatial distribution of contaminants; b) graphical displays that present the available data in their spatial context; c) sample values for data on maps or cross-sections; d) colours, grey scales, or symbols to high-light the locations of the highest sample values; e) kriging for the purpose of interpolation and not extrapolation; and f) quadrants or other forms of local statistics to assist the reader in understanding and evaluating decisions about statistical populations and trends?	
Outliers	24.	For all distributions has the investigator: a) used rank correlation as an alternative to linear correlation to reduce sensitivity to outliers when summarizing the relationship between two variables; b) used probability plots, scatter plots and data postings to identify outliers; c) determined whether the existence of outliers requires that any critical assumptions need to be modified; d) determined the reasons for the existence of the outlier; e) documented the reasons for and provided all relevant information about any outlier value that has been discarded; and f) taken a new sample at a random location within one metre of a discarded outlier sample?	

STATISTICAL ANALYSIS AND INTERPRETATION *Assumptions*	25.	Has the investigator a) described the statistical tools and procedures used to analyze and interpret the data along with their underlying assumptions; b) included calculations and assumptions for population standard deviations estimated for the purposes of a confidence interval calculation; c) provided rationale for method used to deal with non-detectable data; d) used a nonparametric alternative as a way of checking the sensitivity of the conclusion to the distribution assumption; and e) included a statement about the uncertainty of all estimated or predicted values?	
Calculations	26.	Has the investigator: a) calculated percentiles in normal, lognormal or exponential distribution models; and b) described how percentiles were calculated?	
Probability maps	27.	Have probability maps been included to show that there is less than a 5% chance of making a false negative error about the quality of material?	
CONCLUSIONS AND RECOMMENDATIONS *Conclusions*	28.	Has the investigator: a) provided clear and unambiguous conclusions with specific references to the analysis and interpretations that support them; b) accompanied each conclusion with a discussion of how it is affected by any underlying assumptions, by the accuracy and precision of the available sample data and by the uncertainty in estimated or predicted values; c) classified material based on the data being demonstrably representative of one population; and, for that data set: the upper 90th percentile of the sample concentrations is less than the criterion concentration; and the upper 95 per cent confidence limit of the average concentration of the samples is less than the criterion concentration; and no sample within the data set has a concentration exceeding two times the criterion concentration?	
Recommendations	29.	Has the investigator: d) provided clear and unambiguous recommendations; e) informed the client of any other issues of potential concern outside of the goals of the study; and f) provided a rationale with any recommendations, for further investigation?	
REFERENCES *Complete Information*	30.	Has the investigator referenced: a) all data sources, previous studies and other sources (including interviews) that contributed information to the study; and b) any technical literature that provides additional detail on procedures used in the study?	
APPENDICES *QA/QC*	31.	Has the investigator provided: a) analytical laboratory results, either in printed form or on a diskette (Excel preferred) (mandatory requirement); b) laboratory QA/QC procedures, sampling protocol and the results of check analyses (mandatory requirement); c) drill logs and test pit logs (mandatory requirement); and d) a site map showing sampling locations (mandatory requirement)?	
Documentation	32.	Has the investigator included: a) details of statistical computations omitted from the main body of the report; and b) the name and version of the computer software used for the database compilation and the statistical analysis, or a brief description and a reference for any other non-commercial software used in the study?	

Detailed Site Investigation Summary

Using the information gleaned from the preceding checklists, please provide a summary in the site investigation report containing the following information:

- investigation work quality and thoroughness
- the need for additional investigation
- the need for a site visit by ministry staff
- levels of certainty
- compliance with the ministry's legislation, regulations and policy, criteria and guidelines, and
- sign-off sheets appropriately signed.

Statement of objectives

Description of investigation

- including what parameters were tested and why

Rationale for sampling program

- sampling locations and parameters
- sampling rationale

Data presentation

- chemistry data
- hydrogeologic data
- other

Data interpretation and evaluation

- areas of environmental concern
- areas not of environmental concern
- contaminant migration
- level of confidence

Recommendations

- need for further investigation
- assessment of recommendations

Soil Sampling Methodology[2]

There are two common methods of soil sampling: grab samples and composite samples. A grab sample is a sample taken from one specific location, at one time. A composite sample is a combination of smaller samples taken at different locations or at different times. For the identification of volatile contamination, grab samples should be taken.

The sampling should proceed from the least contaminated to the most contaminated site.

The number of field samples that are required is dependent upon the type of contaminant that is being sampled and the knowledge about its distribution throughout the contaminated site (if available).

Individual grab soil samples should be collected at locations throughout the hot spot site. If possible, these should be randomly selected and equally spaced. However, the presence of notable differences in physical soil qualities (such as colour) may necessitate the preferential selection of a sub-set of sampling locations.

Soil samples should be collected using a stainless trowel or shovel, and be collected from the top 10 cm depth (surface soils). Samples will be deposited into a stainless steel tray and will be stirred into a homogenous mixture. Samples will then be placed into one or more 125 mL / 250 mL glass jars.

Pre-sample preparation
This preparation involves:
- identification/location of soil sampling sites
- filling out of field data sheet
- preparation of sampling jars
- identification/location of soil sampling sites

Local background reference sites must be identified, selected, and documented in addition to the suspected contaminated site where a DSI is to be conducted. The next step is to check available soil, terrain, or surficial geology maps to determine the type of surficial (genetic) material at the background reference site.

Wherever possible, the local background reference site is to be located such that it has the same surficial (genetic) material as the suspect contaminated site.

If information on soils and terrain are not available for the site, a terrain survey for the site is required to be conducted.

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[2] Suggested soil sampling approach: Individuals wishing to determine site-specific local background soil contaminant concentrations for their site may use the soil sampling approach (BC Technical Guidance on Contaminated Sites 16, Annexure 1).
This section is extracted from Tab #4: Sampling and Analysis of Hydrocarbon Contaminated Soil. Additional information on field sampling: http://www.env.gov.bc.ca/epd/wamr/labsys/lab_meth_manual.html#field and http://www.epa.gov/oust/cat/pracgw.pdf
POPs Analysis: http://www.chem.unep.ch/pops/laboratory/analytical_guidance_en.pdf

Wherever possible, the local background reference site should be approximately 1 ha in size. At any reference site, a minimum of four sampling points (randomly selected soil sampling locations) should be identified as follows:
- Locate the approximate the centre of the site.
- Divide the site through the centre point into two halves. This is the division line.
- Draw a line perpendicular to the division line through the centre to further divide the site into four quadrants. This is the perpendicular line.
- Randomly select one soil sampling location for each of the four recommended 40 x 40 m quadrants. The sampling location must be designated with two numbers. The first is the number of metres perpendicular to the division line; and the second is the number of metres the sampling site is located to the right or left of the perpendicular, depending on the quadrant one is working in.

Once the sampling locations have been selected, a minimum of three soil samples should be collected at each soil sampling point:
- a surface sample, obtained from 0 m to 0.1 m from the surface of the site
- a shallow sub-surface sample obtained from 0.5 m to 0.6 m from the surface of the site;
- a deep sub-surface sample obtained from 0.9 m to 1.0 m from the surface of the site.

Using this approach, a minimum of 12 discrete soil samples would be collected from the four quadrants of the reference site.

For a suspected contaminated site, detailed site investigations focus on suspect areas and step-outs to be used from suspect locations of between 5 and 7 m, and grid sampling of between 10 and 20 m in larger suspect areas. (BC Technical Guidance on Contaminated sites 1)

Detailed site investigations define the lateral and vertical extent, magnitude, and variability of contamination, and provide estimates of contaminant distributions, substance concentration means, upper confidence limits of the means, 90th percentiles, and other relevant details.

Filling out of field data sheet
The POPs data sheet is a hot spot survey form and comprises of Hot-Spot Identification Questionnaire. See DSI checklist.

Preparation of sampling jars
Samples are collected in a stainless steel tray and stirred into a homogenous mixture. Samples are then separately placed into one or more 125 mL / 250 mL glass jars.

General soil sample - collection and handling procedures.
The essential prerequisites are as follows.
- Use clean sample tools composed of non-reactive materials, such as stainless steel hand augers.
- Tools should be thoroughly cleansed with steam, pressured hot water.
- Samples should be collected in clean glass jars with tight-fitting lids.
- Samples should be transported to the lab within 24 hours.

Collection methods

There are several different methods that can be used to collect soil samples, depending upon the depth of the samples to be taken and the soil characteristics of the site.

It has become common practice to use organic vapour detectors (OVDs) to sample for soil contamination. Although this technique is a useful method for identifying the presence of contamination, it is not ideal when taking quantitative measurements. The results are often quite different from those obtained from laboratory analysis. OVDs may be used as site-screening tools to determine the general location and degree of contamination, but sample collection for laboratory analysis is absolutely necessary.

All sampling equipment should be made of either stainless steel or polytetrafluoroethylene (e.g., Teflon). A clean stainless steel trowel, scoop, or gloved hands should be used to sample the soil. If this is not possible, a backhoe may be used. To prevent loss of volatiles, samples should be gathered from freshly exposed soil and preserved as soon as possible after the excavation. The equipment used for sample collection should not be the same as that used to advance the hole. Clean gloves should be worn and should be changed before each new sample is collected. When possible, a different set of equipment should be used for each sample collection. When this is not possible, the equipment should be cleaned between each sampling event

For test pits, boreholes, and surface sampling, the location and number of samples required are site specific, and will depend on the type of contaminant, its mobility in the environment, and the physical features of the site. The preliminary site assessment and site-screening procedures should be used to determine the appropriate number and location of samples to be taken.

An adequate number of sampling locations should be established in order to determine the horizontal and vertical extent of soil contamination. The sampling density should be increased in areas of anomalies. If no information is available for predicting the location of hot spots, a grid pattern can be used to identify sampling locations.

A sufficient number of samples should be collected from each sampling location to analyze for all parameters as well as soil characteristics. The soil sample should consist of soil particles not greater than 2 mm. Heterogeneous spatial nature of soil makes collection of representative samples difficult, requiring a larger number of spatially distributed samples than other media. Temporal variations can generally be ignored

General in situ investigation and characterization guidance

An in-situ discrete sample is the material:
- collected from similar in situ fill or soil at one location
- confined to collection within a contiguous volume of 1 m^3
- collected over a maximum depth of 0.5 m within the upper 1 m from the existing site surface, or from an identifiable historical site surface; or collected over a maximum depth of 1 m at depths greater than 1 m from the surface
- not collected from two distinct fill or soil zones
- not collected on two sides of an air/water interface (or unsaturated/saturated soil zone interface)
- not made up of a mixture of obviously contaminated material and obviously non-contaminated material as determined by field observations such as sight, smell, gas

metre, etc., even if these materials have similar physical characteristics (e.g., both are silty sands)

The volume that an in situ discrete sample represents is:
- 10 m^3 of material designated as waste, industrial, or commercial quality, or
- 5 m^3 of material designated as hazardous waste.

Use of step-out sampling at hot spots

When an analysis result for an in-situ discrete sample exceeds the numerical standards relevant to the existing or intended site use, then step-out sampling is recommended. At each step-out location, similar fill or soil at relatively equivalent depths is sampled.

Where the in situ discrete material is classified as commercial or industrial quality, three step-outs should be collected for analysis at a distance of no more than 7 m from the original discrete sample location, and preferably at equal distances from each other along the circumference of a circle with a 7 m maximum radius from the original discrete sample location.

Where the in situ discrete material is classified as waste, four step-outs should be collected for analysis at a distance of no more than 7 m from the original discrete sample location, and preferably at equal distances from each other along a circle with a 7 m maximum radius from the original discrete sample location.

Where the in situ discrete material is classified as hazardous waste, four step-outs should be collected for analysis at a distance of no more than 4 m from the original discrete sample location, and preferably at equal distances from each other along a circle with a 4 m maximum radius from the original discrete sample location.

Confirmation of adequate remediation

If chemical concentrations in step-out samples are below the numerical soil remediation standards applicable to the existing or intended site use, then the following actions should be taken:
- 10 m^3 of contaminated material (5 m^3 for hazardous waste), as characterized by the original in situ discrete sample, should be excavated and managed, treated or disposed of appropriately.
- Following excavation, the remaining material in the walls and floor of the excavation should be sampled and analyzed to confirm removal of all contaminated material.

The recommended practice for this confirmation of remediation is as follows:
- Discrete samples should be collected from each excavation surface in the following manner.
    o From any excavation surface, one discrete confirmation sample should be collected such that there is at least one sample within a grid based on 10-m increments (5-m increments for hazardous waste). More closely spaced confirmation sampling may be necessary where thin identifiable layers are suspect.
    o Samples should be collected within a 0.25 m perpendicular distance from a face or excavation floor.
    o For commercial or industrial quality material, up to four discrete samples collected within one orientation (i.e., vertical wall or horizontal surface) may

be composited.
- o For waste material, up to two discrete confirmation samples may be composited.
- o Where the original discrete sample is hazardous waste, only discrete confirmatory samples should be analyzed.

- Analysis of samples for confirmation of concentration
  - o If composites are used, then an n-sample composite is compliant only if its concentration is below the regulatory or criterion limit divided by n.
  - o For composites that are noncompliant, follow-up analysis of each of the discrete samples is required.
    - Where confirmation analysis results are less than site remediation standards, no further action is required.
    - Where confirmation analysis results exceed site remediation standards, each discrete confirmation sample should be analyzed. Contaminated material in the location indicated by these results should then be excavated. Excavation should proceed in maximum 10-m^3 increments (5-m^3 increments for hazardous waste), followed by confirmation sampling.

Identifying additional contamination

If substance concentrations in one or more of the step-out samples are above the numerical soil remediation standards applicable to the existing or intended site use, then the following actions should be taken.

- 10 m^3 of contaminated material (5 m^3 if hazardous waste) around the original discrete sample and the step-out samples are classified as exceeding the numerical remediation standards, as is all material in a similar depth strata or type between these sampling points.
- Another set of step-out sampling and analyses should be completed and the above procedure repeated until such time as all step-outs are below remediation standards for the existing or intended site use
- Classified material should be excavated and appropriately managed, treated, or disposed of, followed by confirmation sampling and analysis as outlined above.

Surface sampling

To retrieve the sample, general collection procedures should be followed. Alternatively, a soil punch may be used. The advantage of a soil punch is that it retains the sample with the soil core intact.

For slightly deeper samples, a bucket auger may be used, but the sample gathered will be a combination of soil at the surface and at greater depths.

Test pits: a clean backhoe should be used to excavate the pit. All excavated material should be placed on a tarp. If free product is present in the pit at a thickness greater than 2 mm the same should be pumped out before sampling the soil.

To retrieve the sample, the general collection procedures should be followed. Representative samples should be collected each time a different soil type is encountered. Samples should be taken from the areas where it is likely that the highest degree of contamination is present. The bottom sampling depth will be dependent upon the characteristics of the particular site and

determined through pre-screening methods.

Borehole installation: Soil borings should be advanced using a power auger drill. Borings should extend to the water table, or at least 1.5 m below the base of the contamination.

Soil samples often exhibit geological variability. A soil sample is generally not a homogeneous mass, but rather a heterogeneous body of material. Samples should therefore be collected at least every 1.5 m and at changes in lithology. Special consideration should be given to the sampling of the vadose zone, as it is an important transition area between the soil and the groundwater. A Split-spoon sampler should be employed to obtain depth specific samples.

Soil pile (excavated soil); Samples should be taken from the areas where it is likely that the highest degree of contamination is present. To retrieve the sample, the general collection procedures should be followed.

Tank pit: If free product is present in the pit at a level greater than 2 mm, Free Product Sampling Procedures (FPSP) should be followed. All free product must be pumped out before sampling the soil as described earlier. Samples should be taken from the areas where it is likely that the highest degree of contamination is present; the "Jar Headspace Test", as described below, may be used to help determine the areas of greatest contamination.

The jar headspace procedure is a quick and simple field screening procedure used to determine the presence of volatile organic compounds in soil or water, before a full site assessment is conducted. The procedure involves collecting a soil or water sample, placing it in an air-tight container and then analyzing the headspace vapour using a portable analytical instrument. The "headspace" is the area between the sample and the top of the container.

The cleaning of soil sampling equipment involves the use of the following:
- gloves , rinsed with clean water
- equipment, scrubbed with a suitable detergent formulation
- equipment, then rinse with clean water (3×), acetone and hexane

No lubricants should be used on the drill bits or rods that are used to excavate boreholes. Only non-petroleum vegetable oil based lubricants should be used on the external surfaces of the drilling equipment that may come into contact with the drill rods. After each borehole is extracted, the augers, bits, and rods used during the drilling should be washed with lab detergent, then rinsed thoroughly with de-ionized rinse water.

Soil sampling steps
These steps include the following:
- All sampling equipment (dredge, mixing tray, spoon, etc.) should be thoroughly cleaned with metals-free soap and de-ionized water prior to sampling at each site. Where analyses require, chemical solvents such as hexane and acetone may be used to ensure all residues are dissolved from equipment surfaces.
- Soil samples should be collected using a stainless steel core sampler, trowel or shovel.
- Samples are collected in a stainless steel tray and stirred into a homogenous mixture.
- Samples are then placed into one or more separate glass jars.

General sampling precautions

Precautions must be taken to prevent the loss of contaminant mass from the sample by volatilization or biodegradation. These precautions include collecting samples in appropriate sample containers and appropriately preserving them.

In order to prevent the introduction of contaminants into the sample from another source, sampling equipment should be thoroughly cleansed between sample locations, and locations should be sampled in order of increasing contaminant concentration, wherever possible.

Sample blanks

Three types of quality control blanks are used during sampling:
- **Trip Blanks:** used to verify if sample contamination occurred in the sample containers and/or as a result of sample cross contamination during sample transport and storage.
- **Field Blank:** used to verify if sample contamination occurred as a result of reagent and/or environmental contamination, such as from contaminated air at the sampling location.
- **Equipment Blanks:** designed to check for contamination from sampling equipment (e.g., pumps and bailers). Equipment blanks are useful for evaluating the effectiveness of equipment decontamination procedures.

Blank preparation

To prepare blanks, he same sampling containers for collecting field samples should be used, but with contaminant-free (blank) water. A blank of each type for every 20 samples should be prepared.
- **Trip Blanks:** Prepare by filling sample containers prior to going into the field. These blanks are carried with the field samples in the sample cooler, and are not opened in the field
- **Field Blanks:** Prepare by pouring blank water from a clean container into a clean sample container in the field at the same time of sample collection.
- **Equipment Blanks:** Prepare in the field by pouring blank water into the bailer of the well, and process as if they were field samples.

Sample preservation methods

Preservation methods will vary depending on the type of POPs For example, methods for preserving PDB samples include the following
- Ideally, the samples should be stored at -20°C from the time of collection till analysis.
- Keep the samples in the mL amber jars (Teflon can also be used). Both Teflon and/or glass will have to be cleaned with solvents and baked before usage

Quality assurance samples
These include:

QA Sample	Purpose
Blank	Sample contamination
Field duplicates (split analysis of same sample)	Sampling precision
Lab duplicates	Method precision
Spiked sample	Matrix effects
Reference standard	Instrument bias
Duplicate reference standard (e.g., bias and precision)	Instrument accuracy
Field replicate (two samples from same location)	Repeatability of sampling

Sampling Considerations for Soil:
- medium of direct contact exposure
- often main source of chemicals released into other media

Quality control duplicates
The collection of duplicate samples provides for the evaluation of the laboratory's performance by comparing analytical results of two samples from the same location. A minimum of one set of duplicates should be collected for every 20 samples.

Obtaining duplicate samples in soil requires homogenization of the sample aliquot prior to filling sample containers. This should be accomplished by filling a properly decontaminated stainless steel tray or bowl and mixing it with a clean instrument. Once mixing is completed, the sample should be divided in half, and containers should be filled by scooping material alternatively from each half.

Groundwater Sampling Methodology[3]

Groundwater plume is continuous and easier to measure than soil contamination. Temporal variations may be moderate depending on the characteristics of the medium (flow ranging from a few metres per day for gravel to a fraction of a metre per year for clay). The exclusion of particles from collected groundwater is an important consideration as the particles most likely reflect the disturbance caused by the well installation and sampling, and not the true groundwater conditions.

Sample extraction
The rate at which a well is sampled should not exceed the rate at which the well was purged. Low sampling rates, approximately 0.1 L/min, are suggested.

Sample withdrawal methods include the use of pumps, compressed air, syringe sampler, and bailers. The selection of the sampling method must be based on the parameters that are to be monitored, the depth from which the sample is collected, and the diameter of the well (Piteau, 1990).

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[3] "British Columbia Field Sampling Manual" (Ministry of Environment, January 2003).
   Barcelona et al. "Practical Guide for Ground-Water Sampling".(1985)

The primary consideration is to obtain a representative sample of the groundwater body by guarding against mixing the sample with stagnant water in the well casing. This is avoided through adequate purging prior to collecting the sample.

Analysis for routine parameters

Besides quantification of POPs, it is sometimes necessary to carry out analysis of routine parameters to determine whether the remediation strategy will be restricted to POPs decontamination/remediation. The routine parameters monitored in groundwater include pH, redox potential (Eh), dissolved oxygen (DO), specific conductivity, metals, ammonia nitrogen, chloride, and chemical oxygen demand (COD); other parameters may be added to this list on a site specific basis. The standard industry practice is to use a flow through cell to measure the DO, pH, and conductivity.

Routine quarterly sampling and in-situ monitoring will establish the presence of any trends, identify any statistically significant changes, locate contaminant plumes and, most importantly, identify those parameters with values that fail to meet the applicable criteria.

Statistically significant refers to a statistically significant increase or decrease from background values or exceedance of a compliance level for each parameter or constituent being monitored. It is the responsibility of the owner/operator or his agent to choose an appropriate statistical method consistent with the number of samples collected, and distribution pattern of the parameter.

Immiscible layers

It is not uncommon to find formulation of a product (proprietary agrochemical) involving POPs dissolved in a solvent immiscible with or sparingly soluble in water. Immiscible layers may be either light non-aqueous phase liquids (LNAPLs) or dense non-aqueous phase liquids (DNAPLs). LNAPL layers must be sampled before a well is purged. To determine the presence of an immiscible layer, an interface probe should be used to measure the first fluid level in a well. Once this has been recorded, it should be lowered until the immiscible water interface is encountered. The depth interval, or thickness, of a floating immiscible layer can then be established.

Note that *g*roundwater samples collected for analyzing any organic constituents should not be field-filtered prior to laboratory analysis. The recommended container for collection is a solvent rinsed, amber coloured glass with an aluminum foil or Teflon liner cap.

Environmental Properties of POPs

POPs	Adrin	Chlordan	DDT	Dieldrin	Endrin	Heptachlor	Hexachlorobenzene (HCB)	Mirex	Toxaphene
Molecular mass g/mole	364.93	409.76	354.49	380.91	380.92	373.32	284.78	545.55	414 [average]
Density, g/cm²	1.6 (20 °C)	1.59 – 1.63	1.6	1.75 (25 °C)	1.64 (20°C)	1.58	2.044	2.00	1.63
Melting point, °C	104 -105.5 (pure) 49-60 (technical)	106–107	108.5–109	175 -176 (pure) 95 (technical)	226-230 (above 200°C decomposition)	95-96	227-230	485	65-90
Boiling Point, °C	Decomposes	175 (at 2 mm Hg)	260	Decomposes	245 (decomposes)	135-145 (at 1-1.5 mm Hg)	323-326 (sublimes)	No data	>120 (decomposes)
Soil sorption coefficient, log Koc	5.38 to 7.67	4,58-5,57	5.146-6.26	6.67	4.532 (calculated)	4.38	2.56-6.08	3.76	2.47-5.00
Octanol/Water Partition, log Kow	5.68 to 7.40	6.00	4.89-6.914	4.32 to 6.2	3,209-5,339	4.4 -5.5	3.03-6.42	5.28	3.23-5.50
Solubility in water, Sw	0.011 mg/l at 20 °C	56 µg/l at 25°C	1.2-5.5 µg/l at 25°C	0.110 mg/l at 20 °C	220-260 µg/l at 25°C	180 µg/l at 25°C	6 µg/l at 20°C	No data	550 µg/l at 20°C
Vapour pressure	3.1×10^{-6} mm Hg at 20 °C	10^{-6} mm Hg at 20 °C	2.53×10^{-5} Pa at 20 °C	7.50×10^{-5} mm Hg at 20 °C	$3,6 \times 10^{-5}$ Pa at 25 °C; 2.7×10^{-7} mmHg at 25°C	3×10^{-4} mm Hg at 25 °C	1.089×10^{-5} mm Hg at 20 °C	3×10^{-7} mm Hg at 25 °C	0.2 - 0.4 mm Hg at 25 C
Henry's law constant, K_H, atm-m²/mol	5.2×10^{-6} at 25 °C	$4,8 \times 10^{-5}$ at 25°C	1.29×10^{-5}	4.9×10^{-5} at 25°C	5.0×10^{-7}	2.3×10^{-3}	$7,10 \times 10^{-2}$	1.0×10^{-5}	$K_H = 0.005 - 0.21$
Appearance	White, odourless crystals when pure. Technical grades are tan to dark brown with a mild chemical odour.	Pure: off-white powder Technical: colourless to yellowish-brown viscous liquid with an aromatic, pungent odour similar to chlorine	Pure DDT: white, crystalline solid with no odor or taste Technical DDT: white or cream coloured waxy solid wit little or no odor	Present as white crystals or pale tan flakes, odourless to mild chemical odour	Pure: White, odourless, crystalline solid Technical: light tan colour with faint chemical odour	Pure: white powder, camphor-like smell Technical-grade: tan powder, camphor-like smell	White monoclinic crystals or crystalline solid	Pure: White crystalline, odourless solid	Yellow, waxy solid with a chlorine/terpene-like odour

Polychlorinated Biphenyls

Congener Group	Mono chlorobiphenyl	Di chlorobiphenyl	Tri chlorobiphenyl	Tetra chlorobiphenyl	Penta chlorobiphenyl	Hexa chlorobiphenyl	Hepta chlorobiphenyl	Okta chlorobiphenyl	Nona chlorobiphenyl	Deka chlorobiphenyl
Molecular weight (g/mol)	188.7	223.1	257.5	292.0	326.4	360.9	395.3	429.8	464.2	498.7
Density (g/cm³)	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
Melting point (°C)	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
Boiling point (°C)	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
Soil sorption coefficient (log Koc)	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
Octanol/Water Partition (log Kow)	4.3-4.6	4.9-5.3	5.5-5.9	5.6-6.5	6.2-6.5	6.7-7.3	6.7-7	7.1	7.2-8.16	8.26
Water Solubility (g/m³)	1.21-5.5	0.008-0.60	0.003-0.22	0.0043-0.010	0.004-0.02	0.0004-0.0007	0.000045-0.0002	0.0002-0.0003	0.00018-0.0012	0.000001-0.0000761
Vapour Pressure (Pa)	0.9-2.5	0.008-0.60	0.003-0.22	0.002	0.0023-0.051	0.0007-0.012	0.00025	0.0006	-	0.00003
Henry's law coefficient (K_H) atm*m³/mol	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data

Most of the PCB congeners in pure form are colourless, odourless crystals. Commercial PCB mixtures are clear viscous liquids. Viscosity of mixtures increase with the number of chlorine atoms attached to biphenyl. Generally PCBs have low water solubilities and low vapour pressures at 25'C, but they are soluble in many organic solvents, oils, and fats

Polychlorinated dibenzofurans (PCDFs)

	1,3,7,8-TetraCDF	2,3,6,8-TetraCDF	2,3,7,8-TetraCDF	1,2,3,4,8-PentaCDF	1,2,3,7,8-PentaCDF	1,2,3,7,8-PentaCDF	1,2,3,4,7,8-HexaCDF	1,2,3,6,7,8-HexaCDF	1,2,3,7,8,9-HexaCDF	1,2,4,6,7,9-HexaCDF	2,3,4,6,7,8-HexaCDF	1,2,3,4,6,7,8-HeptaCDF
Molecular mass	305.96	305.96	305.96	340.42	340.42	340.42	374.87	374.87	374.87	374.87	374.87	409.31
Density (g/cm3)	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
Melting point (°C)	No data	197-198	219-221	177-178	225-227	196-196.5	225.5-226.5	232-234	No data	180-181	239-240	236-237
Boiling point (°C)	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
Soil sorption coefficient (log Koc)	No data	No data	5.61 (estimated)	No data	No data	No data	No data	No data	No data	No data	No data	No data
Octanol/Water Partition (log Kow)	No data	No data	5.82	6.79	6.79	6.79	No data	No data	No data	No data	No data	7.92
Solubility in water in 25 °C (mg/dm3)	No data	No data	$4.2*10^{-4}$	No data	No data	$2.4*10^{-4}$	$8*10^{-6}$	$1.8*10^{-5}$	No data	No data	No data	$1.4*10^{-5}$
Vapour pressure at 25 °C (mm Hg)	No data	No data	$9.21*10^{-7}$	No data	$2.73*10^{-7}$	$1.63*10^{-7}$	$6.7*10^{-8}$	$6.7*10^{-8}$	$3.74*10^{-8}$	No data	$3.74*10^{-8}$	$1.68*10^{-8}$
Henry's law coefficient (KH) atm*m3/mol	$1.48*10^{-5}$	$1.48*10^{-5}$	$1.48*10^{-5}$	$2.63*10^{-5}$	$2.63*10^{-5}$	$2.63*10^{-5}$	$2.78*10^{-5}$	$2.78*10^{-5}$	$2.78*10^{-5}$	$2.78*10^{-5}$	$2.78*10^{-5}$	$4.1*10^{-6}$

It is a white to pale yellow crystalline powder created from production of coal tar. It is used as an insecticide, in the production of PVC, industrial bleaching and incineration.

Polychlorinated dibenzo-p-dioxins

	Monochlorodibenzo-p-dioxins	Dichlorodibenzo-p-dioxins	Trichlorodibenzo-p-dioxins	Tetrachlorodibenzo-p-dioxins	Pentachlorodibenzo-p-dioxins	Hexachlorodibenzo-p-dioxins	Heptachlorodibenzo-p-dioxins	Oktachlorodibenzo-p-dioxins
Molecular mass	218.6	253.1	287.5	322	356.4	390.9	425.3	459.8
Density (g/dm3)	No data	No data	No data	1.827	No data	No data	No data	No data
Melting point (°C)	89.0-105.5	114-210	128-163	175-306	195-206	238-286	265	330-332
Boiling point (°C)	No data	No data	374	446.5	No data	No data	507.2	485-510
Soil sorption coefficient (log Koc)	No data	No data	No data	No data	No data	No data	No data	No data
Octanol/Water Partition (log Kow)	4.52-5.45	5.86-6.39	6.86-7.45	6.6-8.7	8.64-9.48	9.19-10.4	9.69-11.38	8.78-13.37
Solubility in water in 25 °C (mg/dm3)	0.278-0.417	3.75×10^{-3}-1.67×10^{-2}	4.75×10^{-3}-8.41×10^{-3}	7.9×10^{-6}-6.3×10^{-4}	1.18×10^{-4}	4.42×10^{-6}	2.4×10^{-6}-1.9×10^{-3}	2.27×10^{-9}-7.4×10^{-8}
Vapour pressure at 25 °C (mm Hg)	9.0×10^{-5}-1.3×10^{-4}	9.0×10^{-7}-2.9×10^{-6}	6.46×10^{-8}-7.5×10^{-7}	7.4×10^{-10}-4×10^{-3}	6.6×10^{-10}	3.8×10^{-11}	5.6×10^{-12}-7.4×10^{-8}	8.25×10^{-13}
Henry's law coefficient (KH) atm*m3/mol	82.7×10^{-6}-146.26×10^{-6}	21.02×10^{-6}-80.04×10^{-6}	37.9×10^{-6}	7.01×10^{-6}-101.7×10^{-6}	2.6×10^{-6}	44.6×10^{-6}	1.31×10^{-6}-2.18×10^{-5}	6.74×10^{-6}

Appearance In the pure form, PCDDs are colorless solids or crystals. 2,3,7,8-TCDD is odourless. The odours of the other PCDDs are not known.

2.6 CASE STUDIES

Since this Toolkit is intended for initial adoption in Nigeria and Ghana, it was logical to select POP-contaminated sites that had already been identified in these two countries for the purpose of pilot testing the site investigation process discussed in this module. As well as carefully following the recommended steps in their site investigations, the investigation teams were asked to organize their reports according to the proposed outlines presented in section 2.4. The case studies presented here are in report format. Each case study is treated as a single document (with three parts), so acronyms are only defined the first time they are used.

The Ijora power station in Lagos, Nigeria was selected for investigation because Power Holding Company of Nigeria (PHCN) was a major user of PCB-containing transformer oil between 1921 and 1989. The station is located near the Lagos Lagoon and surrounded by local markets.

The Electricity Company of Ghana Accra Central Station G (Makola) was chosen because it is one of the sites of environmental concern listed by the Ghana Environmental Protection Agency and there are plans for it to be redeveloped into a modern shopping mall. This site hosts the company's main transformer servicing workshop and is suspected to be contaminated with polychlorinated biphenyls (PCBs) due to spillage and improper disposal of transformer oil. The site is in the centre of a very busy market area.

The site investigations, which included borehole drilling, sampling and analysis management site evaluation, were carried out under the supervision of Professor Loretta Li, Chair of the Expert Panel, editor of this Contaminated Site Toolkit, and one of its authors. Besides testing Module 2 of this Toolkit and leading to improvement of the Module, this exercise assisted in capacity building as part of the training courses conducted from October 3-16, 2009. The outcomes of these projects provided two African case studies to be included as examples in this Toolkit. The investigations were restricted by time and budgetary constraints. For example, the information for Stage 1 of the preliminary site information had to be collected in advance, together with exploration of the geo-environmental drilling and laboratory capabilities. Each country had only seven days to complete the PSI stages 1 and 2, including chemical analyses, and then proceed to DSI until completion of sampling, discussion and initial report preparation. The budget constrained, for example, the number of PSI surficial samples which could be analysed, the number of borehole drillings and the number of samples which could be sent for chemical analysis. The results therefore, are not ideal for pilot testing, but they do allow us to illustrate the procedures and principles involved.

Preparation for Site Investigations

In preparation for carrying out the site investigations, the following action items were given to the teams in Nigeria and Ghana.

Site selection

Select one small and simple POP-contaminated site. Identify the potential contaminant of concern, search for historical information about the site including:
- site visits, interviews
- building permits, storage tank record, planning, utilities

- archives, previous reports: environmental, geotechnical, fire inspection
- utilities connections
- physiography/regional information: surficial geology, water wells, aquifers, streams, climatic information, floodplains. If the geological, hydrogeology and surface soil information are not available, only non-intrusive techniques can be used to identify the above factors. Other, do nothing, do not disturb the site situation (i.e. NO ACTION). We will combine the soil/geotechnical with environmental investigation.

Action: Teams in Ghana and Nigeria

Analytical and sampling

1. Laboratory for PCBs: equipment (GC-MC) availability, testing procedures, QA/QC, detection limit, amount of samples required for analysis, storage (i.e., temperature, maximum duration for storage) turnaround time after submission of samples.

Action: Teams in Ghana and Nigeria

2. Based on the potential contaminants of concern (e.g., PCBs), the necessary sampling preparation includes type of bottles to be used, storage conditions (e.g., temperature), and sample shipment conditions and timeframe.

(Action: Loretta Li)

Usually, this information is provided by a certified commercial analytical laboratory. Here are the information provided by Loretta Li for Ghana and Nigeria preparation.

The issues below require the involvement of an environmental chemist with expertise in contaminant analyses. These are not trivial issues and it will not be easy to provide answers that will suit all scenarios. They are very site specific and depend on the type of POPs involved.

(a) Spatial sampling – the depth of the sampling will depend on the geological situation and the extent of contamination. Indeed, it will depend on the type of contamination and the type of sample available to obtain the most representative results. One needs to have collected all the necessary details (see Action item: *Site selection*) before proposing a sampling plan.

Soil samples, as needed for analysis must be at least 100g; for water samples, the amount of water required will depend on the expected level of contamination and particulate level. Or it may be possible to pass water through filters and sorbents, and store those instead of the water. Again, a specialist must assess the situation and decide on the best sample to take. If no chemist is available to provide advice, the safest thing to do is to take 4L water samples.

Samples transported to the lab should, at a minimum, be stored in ice.

(b) Soil and water samples should be kept in Teflon and/or glass bottles (500 mL amber jars for soil and 4L amber bottles for water). All bottles must be cleaned with solvents and baked before usage.

(c) Ideally, all samples should be stored at a minimum of -20°C from the time of collection until analysis. If there is no freezer facility available capable of maintaining this temperature, a less-than-ideal 4°C will suffice.

(d): There are   dozens of methods published and used by different commercial laboratory describing analytical procedures and equipment for analysis of PCBs. Dr. Loretta Li has provided a technical report by DFO (Department of Fishery and Oceans, Canada) which describes the analytical method that they use for PCBs analysis. These have been sent to Ghana and Nigeria.

Borehole drilling for detailed site investigation

1 Find out from the drilling contractors the available drilling techniques for the week scheduled for sampling.

Action: Teams in Ghana and Nigeria

2 Find out which drilling company has experience in environmental sampling?

Questions to ask to the drilling company include the following:
- What techniques do you commonly use for environmental soil sampling?
- Do you have the facility to steam clean a drill rig after each sampling?
- Can you install monitoring wells?
- How do you install a monitoring well?
- Do you use the same borehole for well installation or drill a new one?
- How much time is required for each drilling and installation of a monitoring well?
- What is the maximum depth for each drilling?
- What is the cost—per hour, per day or per borehole?

Note: To minimize the cost and time, one borehole drilling should be able to serve three purposes: to provide geotechnical samples, to provide environmental samples, and to install a groundwater monitoring well (useful for site monitoring including post-monitoring).

3. Select the driller company and book the equipment.
   o *Loretta Li* needs the above (1) and (2) to determine (3). *(Dr. Li provided additional information regarding drilling, prevention of cross-contamination and installation of monitoring wells after drilling.)*
   o List of worker safety precautionary measures and accessories need to be prepared.

Personal Safety Requirements for POP- Site Visits

Each participant should be equipped with the following:

- Disposable gloves (sufficient pairs for one time use in handling each sample)
- N95 mask
- Eye protection goggles
- Disposable Tyvek suit (sufficient for total days of sampling, one day each suit)
- Safety boots or shoes
- Hard hat
- Safety vest

Safety procedures for site visits

- Wear disposable gloves to prevent skin contact with (PCBs)
- Wear a mask to avoid ingestion and inhalation if/when the nature of the PCB-related activities could result in exposure via those routes.
- Use protective equipment to prevent potential eye or skin contact. Depending on the nature of the planned work, the required equipment may include goggles, gloves (nitrile), aprons, coveralls, jackets, pants and footwear (e.g., rubber or neoprene boots/overshoes or disposable boot covers). Protective clothing must be disposable (e.g., Tyvek) or reusable (neoprene). If reusable protective clothing is used, then it must be used only for PCB-related work and must be cleaned and maintained. Reusable protective clothing should be disposed of after 10 days (80 hours) of use or when material becomes cracked/worn, whichever occurs first.
- Prevent PCB exposure through ingestion by practicing good personal hygiene. In addition to wearing gloves to prevent skin contact, personnel involved in PCB-related activities must wash their hands prior to breaks, eating, drinking and smoking. Hand washing must be done using disposable wipes, waterless cleaners, or soap and water.
- Minimize PCB exposure levels through inhalation by providing adequate ventilation and/or using respiratory protection (mask).
- Remove and dispose of all protective wear when you leave the site, or store in a garbage bag for later disposal.

Lessons Learned

These pilot tests have confirmed that the process outlined in Module 2 of the Toolkit works very well and is appropriate for these kinds of sites in developing countries. Here are the specific lessons learned for Nigeria and Ghana:

(1) Diligence in carrying out PSI Stage 1 is vitally important to the success of investigation projects and in the planning of PSI Stage 2 sampling and subsequent DSI. Without adequate background information, there is insufficient basis for the planning of PSI Stage 2 sampling.

(2) For both the Nigerian and Ghanaian sites, there was a serious lack of site geology, hydrogeological information, and power station data related to the types and composition of transformer oil being used. Such lack of basic date is common for many developing countries. Since the geological, hydrogeolgical and soil conditions were unknown in both

cases, geotechnical sampling and environmental sampling were performed at the same time as other aspects of the studies. It is important to note that the two boreholes that were not used as monitoring wells were backfilled with bentonite to prevent migration of contaminants.

(3) An experienced and responsible driller should be on site to provide proper instruction to the drilling crew members. Basic drilling crew safety facilities and safety footwear were lacking in the reported studies.

(4) Basic drilling equipment for profile soil sampling, such as a hollow stem auger and a solid stem auger, were not available in Nigeria. The manual drilling rig provided for DSI was an outmoded "Shell and Auger boring" instrument. This type of equipment is not suitable for geo-environmental sampling. Special advice and care were needed to prevent cross-contamination.

(5) There are many lessons which can be learnt through these exercises, not only technical, but also including improvement of time management and the need for careful and accurate recording and reporting, effective decision-making and teamwork.

Multi-disciplinary Experts Who Participated in the Case Studies:

Nigeria:

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Adeoti Lukeman (Dr.) Geophysics University of Lagos
Adesipe Kunle Environmental Technologist UNIDO Consultant
Afolabi Faosat, Chief Environmental Scientist, Federal Ministry of Environment
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Laniyan Babatunde, Environmental Manager, UNIDO Consultant
Nwosu Chike, Environmental Officer, Jawara Environmental
Osibanjo Oladele (Prof.), Director, Basel Convention Coordinating Centre for Africa
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Oketola, Adebola (Dr.), Research Associate, Basel Convention Coordinating Centre,
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Geotechnical/hydrogeology work and drilling were contracted to Dr. Lukeman Adeoti

The PSI stage 1, PSI stage 2 and DSI draft reports were initially prepared by Professor
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Geotechnical/hydrogeology work and drilling were contracted to Mr. Dennis Kulekey.

The PSI stage 1, PSI stage 2 and DSI draft reports were initially prepared by Dr. Shiloh Osai
and extensively revised by Loretta Li.

The assistance of each of these participants is gratefully acknowledged.

SITE INVESTIGATION CASE STUDY: NIGERIA

Old Power Generating Station, Ijora, Lagos, Nigeria
Preliminary Site Investigation – Stage 1

Executive Summary

A preliminary site investigation (PSI) Stage 1 was conducted at the old power generating station at Ijora in Lagos, Nigeria. The objective was to determine the likelihood of potential contamination by persistent organic pollutants (POPs).

Since historical records from this location were not available, information was gathered from a site visit, a review of climate and geology records from nearby locations, and interviews with the Head of the Power Holding Company of Nigeria (PHCN), Ijora, the Principal Manager of the Laboratory, and other personnel from the company.

The station has two sites, A and B. Site A, which includes a repair workshop, was established in 1921 while Site B was commissioned in 1956 for power generation and transmission to Lagos and its environs. Power generation was stopped at Site A in 1978, and at Site B in 1990. Site A is currently used as a transformer repair station, while Site B houses offices and a laboratory.

The potential contaminants of concern are polychlorinated biphenyls (PCBs), which are associated with the use of transformer oil at this station. The site assessment indicated a possible likelihood of soil and groundwater contamination above international standards. Due to the extent of contamination, a radius of between 200 m and 500 m was chosen for the study.

1 INTRODUCTION

There are four major sources of POPs in Nigeria: pesticides, transformer oil, open burning, and incineration. The old power generating station at Ijora in Lagos, Nigeria was investigated for POPs contamination. The objective of the PSI Stage 1 investigation was to determine the likelihood of potential POP contamination at the station.

Scope

The scope of this work is to gather and produce adequate data as a baseline to meet the objectives stated in Module 2 (see sections 2.2 and 2.5). The scope of this PSI includes the following:

- a review of historical data and current records
- a review of regional climate, geological, topography, and hydrogeological information
- site visits: the first visit on September 23, 2009 was to observe site conditions and second visit on October 5, 2009 was to conduct the investigation

2 SITE LOCATION

The power station, which is located in the heart of Lagos, covers a large area, as shown in Figures N1.1 and N1.2. Site A and Site B contain the repair shops of interest in the investigation. The buildings between the two sites include machine repair shops and storage buildings. There is no civil address available, such as a specific street name or number, and government registry records are also unavailable. The address is Ijora Power Generation and Transmission Station (Site A and Site B). The Lat/Long Coordinates are approximately 6^0 27 59.83`N; $3^0$ 22 35.45`E (North), and 6^0 27 57.49`N; $3^0$ 22 35.43`E (South).

Figure N1.1
Location of Ijora Power Generating Station in Lagos, Nigeria
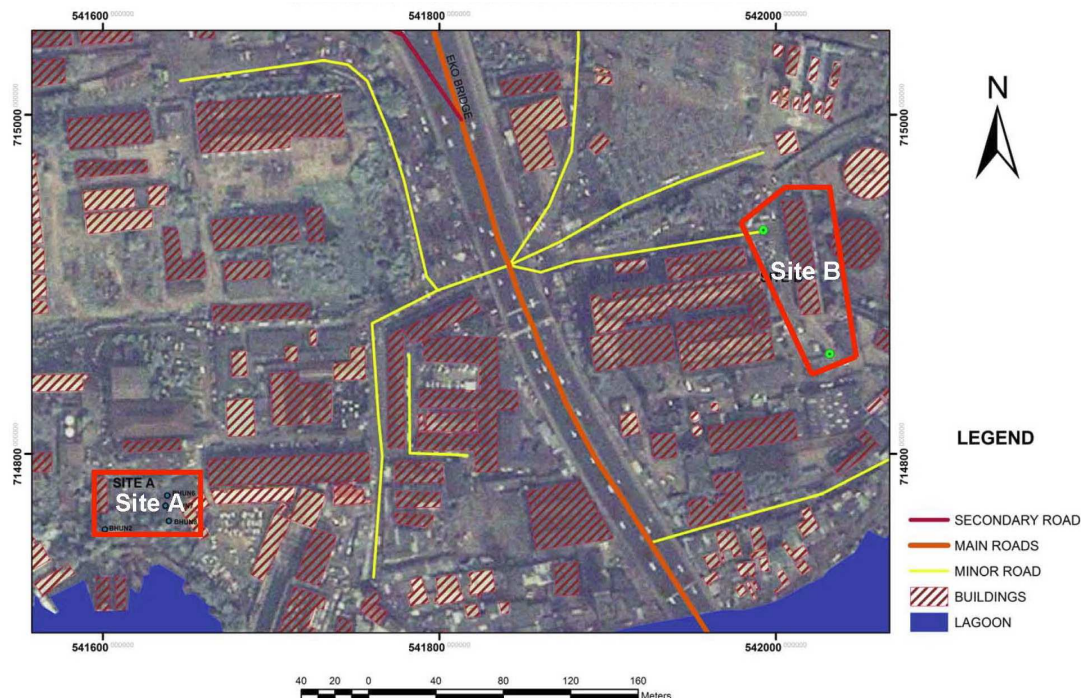
Figure N1.2
Satellite view of Ijora Power Generating Station in Lagos, Nigeria

Site Record Review

Since there were no available site records from government registries, a site review, based on interviews, was carried out to establish previous land uses and any additional information with respect to contamination. When power generation and transmission started on Site A in 1921, several transformer oils containing PCBs were used (e.g., Clophen and Askarel). The station worker who was interviewed reported some of the effects of using these oils, including itching. The use of these products ceased in the late 1980s. The head of the station's laboratory, where the quality of the oils are tested, confirmed that the transformer oil used since 1989 does not contain PCBs.

A detailed site plan and map were not available. No underground storage tanks are known to exist, and there is no indication of the site being occupied or used for any other activity before 1921.

2   SITE PHYSIOGRAPHY

Area Description

The station is owned by the National Electric Power Authority (NEPA), which metamorphosed into the Power Holding Company of Nigeria in 2004. The station is divided into two locations, Site A and Site B, which are separated by a street market and a highway bridge.

Site A was established in 1921, while Site B was established in 1956 and commissioned by the Queen of England. Both sites were used for power generation and transmission until 1978 at Site A, and 1982 at Site B. There is a repair workshop at Site A that has been in existence since 1921. Site A was converted into a transformer repair station for the country in 1985. Site B houses offices and a laboratory. Unfortunately, the historical data for the site were unavailable.

Regional Geology

Nigeria, which lies within the mobile belt of Africa affected by the Pan-African orogeny, is sandwiched between the Congo Craton and the geologically more stable and older West African Craton (see Figure N1.3). The diverse rock types of the region can be subdivided into three main groups, in order of increasing age:
- the Basement Complex (500-2,500 million years)
- the Younger Granites   (140-250 million years)
- the Sedimentary Series (recent-120 million years)

The geology of Nigeria reveals that various units of the geological succession range in age from the Precambrian to the Quaternary periods. The Precambrian rocks are partly overlain by Cretaceous sediments, which are approximately 120 million years old. More recent sediments overlie the Cretaceous sediments in some areas, but lie directly on the Precambrian in others (Kogbe, 1974).
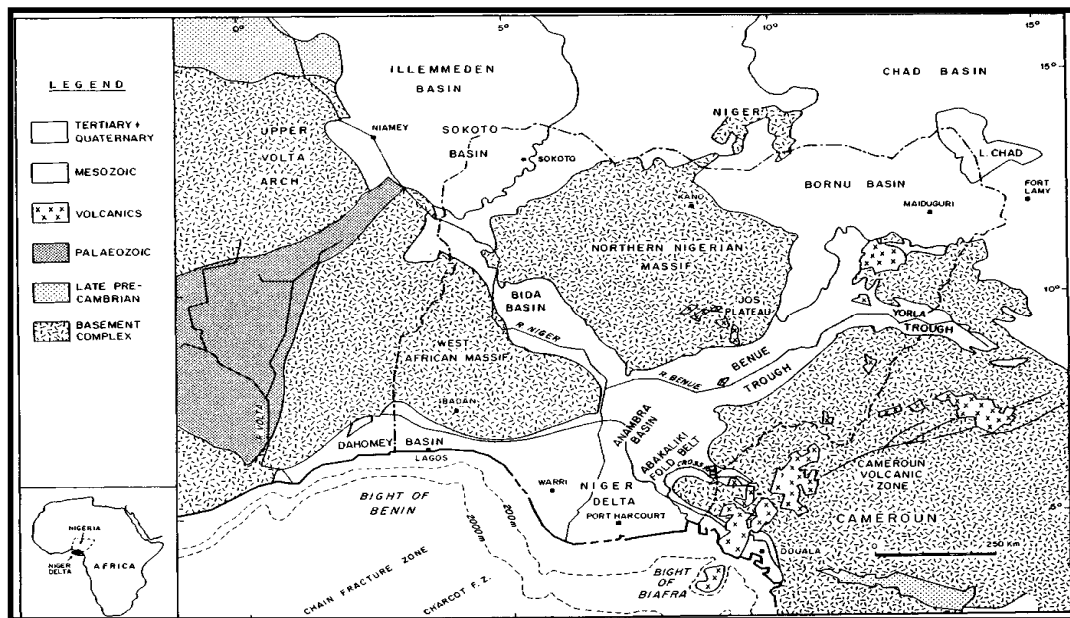
Figure N1.3
Geological Map of Nigeria

Geology of Lagos state

Lagos State lies in Southwestern Nigeria and the formations found here occur within the Sedimentary Series (see Figure N1.4). The state overlies the Dahomey basin, which extends

almost from Accra in Ghana, through the Republics of Togo and Benin, to Nigeria where it is separated from the Niger Delta basin by the Okitipupa ridge at the Benin hinge flank. According to Jones and Hockey (1964), the geology of Southwestern Nigeria reveals a sedimentary basin that is classified under five major formations according to their geological age of formation (from Recent to Cretacous): the Littoral and the Lagoon deposits, Coastal Plain sands, the Ilaro formation, the Ewekoro formation and the Abeokuta formation overlying the crystalline basement complex. Four of these formations, excluding Ilaro, constitute aquifers in the Dahomey Basin, from which the geological section of Lagos was drawn. The Ilaro formation is composed predominantly of shaley clay (argillaceous sediments). Limestone forms the aquifer material in the Ewekoro formation while sands and gravels constitute the materials in aquifers of the recent sediments. Coastal plain sands and Abeokuta formations contain brackish water.
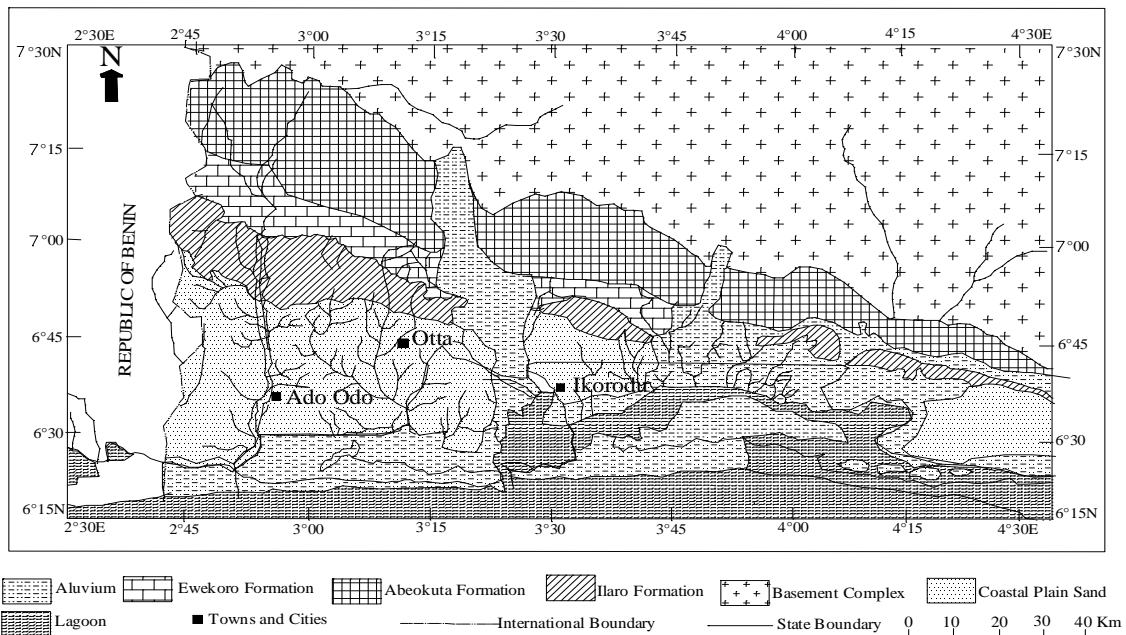
Figure N1.4
Geological Map of Nigeria

Site Geology and Groundwater Flow

Since there were no geological data for the site, and climate, topography and groundwater conditions were not available from government and appropriate agencies, data from other relevant locations in Lagos State, with similar geological and hydrogeological patterns, were reviewed.

Based on the geology of the state, the site is sedimentary. The groundwater flow direction, the depth of the water table and aquifer thickness are unknown.

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Geomorphology, Climate and Vegetation

Topographically, Lagos State lies entirely within the coastal plain of Nigeria, which is characterized by sand bars, lagoons and creeks. The land on the northern fringe of the state has soils that do not rise very much above sea level. Steady coastal retreat is occurring in some areas. The state is endowed with very little arable land, with four identifiable soil groups:

- Juvenile soil on recent windborne sands occurs on the western half of the coastal margin.
- Juvenile soil on fluviomarine alluvium (mangrove swamp) covers the rest of the coastal area towards the east.
- Hydromorphic soil occurs in the middle and northern-eastern sections.
- Red ferrallitic soil occurs on discontinuous patches throughout the Lagos State.

Two climatic seasons are experienced in the state, and in Nigeria as a whole: the rainy and dry seasons. The former is between March and October while the latter spans from November to February. Lagos experiences a humid tropical climate that is characterized by high temperatures as a result of its proximity to the equator. The annual rainfall of Lagos State is 1,636.1 mm (Abegunde, 1987). The highest temperatures occur in November-December and February-March during the short dry season. The lowest temperatures occur at the peak of the rainy season in July, with a resultant mean relative humidity of 88% (Abegunde, 1987). During the wet season months, southwest winds prevail. From November to February, northeast winds sweep in the dry season. The average daily temperature is 30^0C. The relative humidity is high throughout the year, generally not falling below 70% to 80%.

The main vegetation types identifiable in Lagos State include swamp forest and tropical rainforest. The swamp forests are a combination of mangrove forest and coastal vegetation developed under the brackish conditions of the coastal areas and the swamp of the freshwater lagoons and estuaries. Tropical rainforest stretches from the west of Lagos in Ikeja through Ikorodu to an area slightly north of Epe. The latter area contains such economically valuable trees as teak, tripochiton, selectrocyclon (Arere), banclea diderrichil (Opepe) and terminahia (Idigbo). The creeks, lagoons and rivers act as arteries that carry huge quantities of logs from out-of-state sources to Lagos. The old power generating station is covered mainly by giant grass as secondary vegetation. It falls within the tropical rainforest zone with various species of the mangrove swamp vegetation, although the vegetation has given way to urban development.

3 USAGE AND ACTIVITES OF SITE AND ADJACENT AREAS

Current Use of Site

Site A is currently used as a national transformer repair station or workshop, while Site B contains office buildings, a laboratory, transformer storage, a transformer oil drum storage site, abandoned/used vehicles and a warehouse containing kegs of obsolete chemicals.

Current Use of Surrounding Area

The power generating station is located at Ijora Olopa in Apapa Local Government Area of Lagos State. The station is accessible from the Ijora road, which links the Federal Ministry of Work Central Division, Ijora and the Ajebo market. The station is located in a mixed commercial and industrial area along busy major roads (Eko Bridge and Carter Bridge). Due to the potential extent of contamination, a radius of between 200 m and 500 m was chosen for the study. The station is surrounded by office buildings (e.g., JB Company, Water Corporation), a lagoon, a highway, a fish market, refrigerator repair centres, and a storage warehouse, among others. No residential premises were observed around these sites.

Site A is surrounded by a lagoon to the south, an office building to the north, Julius Berger Construction Company to the east, and a PHCN building to the west. There is a fish market between Sites A and B. Site B is surrounded by the fish market, Lagos State Water Corporation office and power transmission lines.

Surface Water and Water Supply

No flowing surface water traverses the station but the lagoon flushes the southern part of Site A. The water supply at the station is from the public water supply (Lagos State Water Corporation).

4   SITE RECONNAISSANCE AND POTENTIAL CONTAMINATION IDENTIFIED

As mentioned previously, site visits were conducted during the rainy season, on September 23 and October 5, 2009.

Surface Conditions and Drainage

Site A is approximately 65.2 m long by 65 m wide. Approximately 51.3 m of the width is covered with concrete that is cracked in places, while the rest of the site is bare land formerly used for farming by PHCN staff. The power generation building on Site B was constructed on the lagoon. At Site A, a channel running from the repair workshop discharges directly into the lagoon, and an open drainage system, which traverses the site, also discharges directly into the lagoon (see Figure N1.5). The distance from the drainage – an open channel – to the wall at the northern side of the site was measured to be ~64.5 m. Figure N1.6 shows the activities in Site A.

Figure N1.5
(a) Drainage hole on a concrete slab of the workshop and (b) open channel at the eastern end of Site A both directly drain into the Lagos Lagoon.

Figure N1.6
Site A (a) the former transformers storage area facing the repair shop (d) and the open channel drainage is the corresponding location of Figure N1.5(b), (b) old transformers within the compound, (c) a worker without protective wear, (d) repair shop (also see Figure N1.5(a))

Site B is mostly concrete paved apart from the transformer oil drum storage area and the transformer storage area that is bare land, as shown in Figure N1.7. No septic systems or open water bodies were seen during the site visits. Abandoned turbines are used in Site B as a waste dump, which discharges directly into the lagoon (Figure N1.7). Figure N1.8 further shows outside the repair shop at Site B and its current situation. Some of the activities of the surrounding area are shown in Figure N1.9. All photos were taken during the site visit on October 6, 2009.

In general, Site B looked much cleaner than Site A, except for the building on the lagoon where power was previously generated. In addition to the observations made in the previous section, the following features were observed:
- cracks in the concrete on Site A
- oil stains in and around Site A, mainly at the workshop
- metal scraps in the sand on top of the concrete in Site A
- abandoned transformers on both sites
- empty transformer oil drums on Site B

Potential Contaminants of Concern

According to information gathered from the personnel of PHCN, and confirmed by the Head of Laboratory, the use of PCB-containing transformer oil (Askarel, Clophen, etc.) was stopped in 1989 at this station.

Since PCB-containing transformer oil is known to have been used at the station in the past, PCBs are the POP of concern for this site. Heavy metals and polycyclical aromatic hydrocarbons (PAHs) are also potential contaminants of concern for this site, but this report (and Toolkit) focuses only on POPs.

Migration Pathways

The migration pathways for the PCBs include the following:
- direct drainage to the lagoon
- groundwater
- air deposition
- soil and sediment
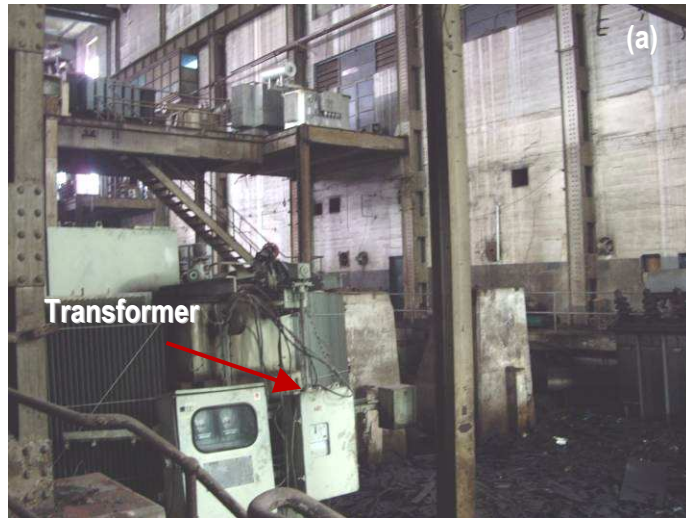
Figure N1.7
The repair shop at Site B, directly connected to the Lagos Lagoon: (a) transformers submerged in liquid, (b) transformer washing water, (c) drainage opening on the concrete slab, (d) garbage dumped into the drainage opening.

Figure N1.8
Outside the repair shop of Site B: (a), (b) and (c) obsolete transformers dumped in the different unpaved areas around the repair shop (Figure N1.6), (d) corroded transformer oil storage drums, many of them rusted and with holes.

Figure N1.9
Surrounding land use around Sites A and B: (a) and (b) open markets under and near the highway bridge, food products including produce (vegetables, fruits), meats, fish and daily items, (c) open markets outside the wall of Site B, (d) auto-repair shop.

Potential Receptors of Concern

There is a high risk of contaminant infiltration through the subsurface and cracks in the concrete slabs, later migrating to the groundwater and then to the lagoon, which is the final sink. Potential receptors of concern in the immediate environment of the station include the staff of PHCN, the people and livestock in the surrounding market, staff of the companies and offices around the station, and small animals seen on the sites such as lizards, ants, earthworms, fish in the lagoon and other microorganisms that live in the sediment. Since the aquifer below the site is not used for drinking water, groundwater contamination resulting from migration of contaminants would likely be of a lower concern.

Based on the site reconnaissance and interview, however, the receptors are at high risk from exposure through dust inhalation, dermal contact, consumption of potentially contaminated fish from the lagoon, and consumption of plants grown on the bare land close to the workshop on Site A.

4 CONCLUSION AND RECOMMENDATIONS

Both Sites A and B are potentially contaminated because of the use of PCB-containing substances   since 1921 and 1956, respectively. It is likely that PCBs have contaminated both sites and the lagoon, which is the final sink of all site discharges. Based on this Stage 1 investigation, there is high potential for the presence of PCBs in all environmental media (i.e., soil, sediment, groundwater, biota, etc.) at this station, which is likely to be above most international standards (no national standard is available for this category of contaminants, and for POPs in general in Nigeria). It is therefore recommended that a PSI Stage 2 be conducted.

5 LIMITATIONS OF THE REPORT

Major limitations during the course of this work include the unavailability of historical data, and government records and information from the appropriate agencies. The required personal safety and protection facilities were either unavailable in Lagos or there were insufficient supplies of items such as   safety masks, proper disposable gloves, disposal shoe-protectors, disposal protective suits, etc.

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Preliminary Site Investigation (PSI-S1) Checklist for Nigeria Case Study October 2009

Section 1	Checklist Preliminary Site Investigation Stage 1 (Items 1–14)	Status Y/N
SUMMARY *Analyses*	1. Does the investigator: a) identify who the major participants are in the investigation; b) state his/her qualifications; c) identify if the study is a first or second stage preliminary site investigation; d) indicate whether the investigation proceeded in stages; e) provide the objectives, methods and procedures that were used in each stage; f) describe the relationship of the two stages; and g) summarize the results, including an evaluation of data that clearly shows the classification, general location and degree of contamination in soil, groundwater, sediments, and surface water?	Y Y Y Y Y Y Y
	2. Does the summary: a) identify what contaminants the analysis program focused on; and b) indicate how reliable the sampling methodology and laboratory analysis was?	Y Y
OBJECTIVES *Goals*	3. Are the goals of the investigation: a) clearly stated; b) in compliance with the scope of work agreed upon with the client; and c) consistent with Ministry of Environment goals and objectives?	Y Y Y
SITE HISTORY & DESCRIPTION *Description of the site*	4. Has the investigator provided: a) a legal description of the property; b) the civic address of the property; c) results from a title search; d) a legal plan from the Land Titles Office; e) information from the ministry on the presence of contaminated sites within 500 metres of the property; f) information from the ministry groundwater section (more relevant for rural properties); g) municipal service plans (if relevant); h) a synopsis of building plans from municipal building inspection departments; i) a municipal zoning plan; j) photos of subject property and adjoining properties; and k) the dates when site visits were conducted?	N N N N N N N N N Y Y

Historical review	5. Has the investigator:	
	a) reviewed the following information;	
	• site plans and diagrams.	Y
	• aerial photographs.	Y
	• Site Registry records. (mandatory, index results & detail reports to be included)	N
	• city directories	N
	• property titles	N
	• fire insurance records	N
	• information provided by current site owners and those knowledgeable about the site	Y
	• previous environmental or geotechnical reports relevant to the site.	N
	b) searched the BC Directory for history of occupiers at subject's civic address;	N
	c) done additional title searches if necessary to determine site ownership history;	N
	d) described the historical activities likely to have been present on site;	Y
	e) listed type of contaminants likely to have been associated with each site activity (past/present);	Y
	f) outlined the mechanism of contamination (how, who, why, source, pathways, receptors); and	Y
	g) speculated on age of contamination?	Y
Maps	6. Has the investigator:	
	a) *provided a site map, including land use, relevant buildings found on site, dimensions in metres and area of property in hectares;*	Y
	b) *reviewed aerial photographs of the site and adjacent environs taken prior to and after development, in preparation of historic uses*	N
	c) *included natural features such as lakes, rivers, streams found at least partially within the boundaries of the property;*	Y
	d) *included constructed features such as underground storage tanks, lagoons, ditches, sumps within buildings, and waste storage areas;*	Y
	e) *provided an area topographic map of 1:20 000 or larger*?	Y
Surface conditions	7. Has the investigator provided:	
	a) information related to topography (e.g., how it relates to possible groundwater flow and direction of surface runoff);	Y
	b) an estimation of the percentage of the site presently occupied by buildings and paved areas;	Y
	c) an estimation of the percentage of the site occupied by buildings and paved areas in past industrial/commercial configurations;	Y
	d) a general description of adjacent property, water resources;	Y
	e) the distance to surface water, drinking water supply sensitive environments;	Y
	f) a discussion of the flood potential of the site?	Y
Groundwater	8. Has:	
	a) an attempt been made to determine if and where septic systems exist on site, using local government files, etc.;	N
	b) an assessment of groundwater vulnerability been provided through information about site soil conditions including texture, structure, thickness, and the content of organic matter and clay minerals;	Y
	c) a general interpretation of groundwater flow and depth been provided by a qualified hydrogeologist; and	Y
	d) the assumption behind interpretations of groundwater depth and movement been provided?	Y

Wells	9. If monitoring wells have been installed near the disposal areas previous to this investigation: a) have the monitoring results been reviewed; b) have data been included that indicate why and when a monitoring well was installed and by whom; and c) has any previous geotechnical investigative work been identified and reviewed?	 N N N
Soil types and soil depths	10. Has the investigator: a) provided soil survey information; b) contacted soil survey personnel, or soil scientists, if no soil survey information is available; c) indicated whether there is visible signs or sources of pollutants on the surface of the soil?	 Y Y Y
Climatic conditions Industrial sites Basic preliminary assumptions about contaminants and migration mechanisms Basic preliminary information about liability	11. Has the investigator provided: a) annual precipitation records; b) along with a description of seasonal variations in precipitation; and c) estimates of infiltration rates? 12. For industrial/commercial sites currently operating: a) has the investigator identified manufacturing processes, raw materials, chemicals or fuels used; b) has the investigator identified the potential waste streams; c) has each waste stream's chemical characteristics, volume, and methods of treatment and disposal been determined; and d) has the presence of electrical transformers or capacitors been determined? 13. Has the investigator: a) provided approximate concentrations and general locations of contaminants (random or non-random, large area extent or confined, near surface or at depth); b) discussed reactivity (soluble or non-soluble, volatile or non-volatile)and the toxicity rating (human & ecological) of the potential contaminants of concern; c) listed activities in neighbouring properties to a distance of at least 300 metres from the site under investigation; d) provided evidence that migration has occurred (reliable or unreliable); and e) examined surface waters (including ditches) for signs of contamination? 14. Does the investigator: a) provide adequate information about any court or administrative actions, ministry orders, Federal charges under the *Fisheries Act*, etc.?	 Y Y Y Y Y Y Y N Y Y Y N N

Old Power Generating Station, Ijora, Lagos, Nigeria
Preliminary Site Investigation – Stage 2

Executive Summary

The PSI Stage 1 concluded that since both Sites A and B, and the Lagos Lagoon, were potentially contaminated with PCBs, a PSI Stage 2 should be conducted.

In Stage 2, surface soil samples were collected from seven different locations in Site A, while, at Site B, five soil samples, and one used oil sample from the abandoned pond in the power generating building, were obtained. The results showed surface contamination of PCBs in Site A with two of the seven surface soil samples exceeding the AENV Tier 1 screening level (Alberta Environment, 2009; see Table 3.1 of Module 3). None of the five surface soil samples from Site B exceeded the screening level.

Since it is likely that the subsurface soil and groundwater are contaminated due to the migration of PCBs, a detailed site investigation was recommended.

1 INTRODUCTION

Stage 1 of the preliminary site investigation suggested that both Sites A and B are potentially contaminated sites with PCB-containing substances used on the sites since 1921 and 1956, respectively. It also seemed likely that PCBs have contaminated the Lagos Lagoon, which is the final sink of all site discharges. Thus it was recommended that a Stage 2 investigation be conducted.

Scope

The objective was to determine if soil and groundwater at the site were contaminated with PCBs at levels above the allowable limits in Table 3.1 of Module 3, due to the historical use of transformer oils at the station.

2 SITE SYNOPSIS

As noted in the PSI Stage 1, Site A is partly concrete with metal scraps buried under the surface soil. The concrete is cracked and contaminants may potentially have migrated downward through the cracks. There is a canal at the southern part of the site that discharges directly into the lagoon (see Figures N1.5). Old transformers are scattered around some areas of the site. Bare land on the site is used for domestic farming by PHCN repair workshop staff. During the site visit, patches of old transformer oil spills were observed on the ground.

Although Site B is mostly bare ground and appears to be cleaner than Site A, the abandoned power generation building area is very untidy and is situated directly on the lagoon (see Figure N1.7). Some areas of the bare land are used to store old transformers, while another area is used to store empty transformer oil drums (see Figure N1.8).

See the Stage 1 report for further details about the sites. A conceptual site model, which is shown in Figure N2.1, was developed based on Stage 1 investigated information.
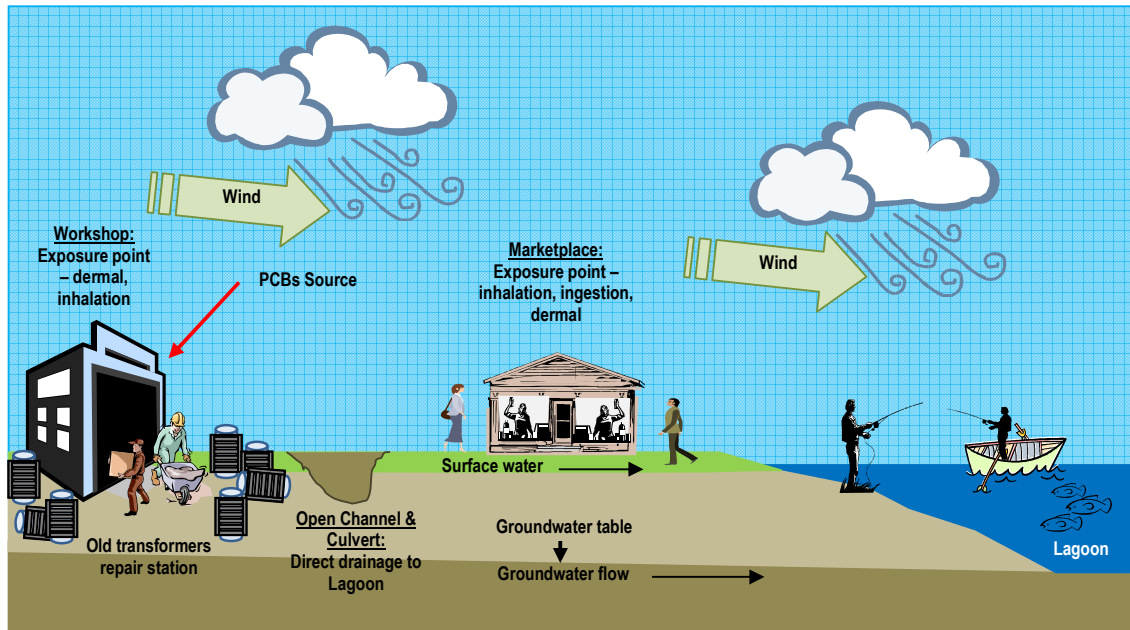
Figure N2.1
PCB-Contaminated Site Conceptual Model

3   INVESTIGATION PLAN

Based on site visits and the PSI Stage 1, surface soil samples were collected from potential hot spots of PCB contamination at both Sites A and B. These samples were sent for laboratory analysis to determine the concentration of PCBs.

Grab samples were collected at seven different points at Site A:
- one sample beside the canal (UN1)
- four samples from the concrete area where soil has accumulated over time (UN2-UN5)
- two samples from bare land formerly used for farming (UN6 and UN7), as shown in Figure N2.2

At Site B, five soil samples and one used oil sample from a pond at the power generating building were collected:
- two soil samples from a transformer storage area very close to the site's main entrance (UNB1 and UNB2; see Figure N1.8, photos (b) and (c))
- two soil samples from the empty transformer oil drum storage area (UNB3 and UNB4; see Figure N1.8, photo (d))
- one soil sample from inside the abandoned power generating building (UNB5; see Figure N1.7, photos (a) and (b))
- one oil sample from the pond inside the building (UNBO1)
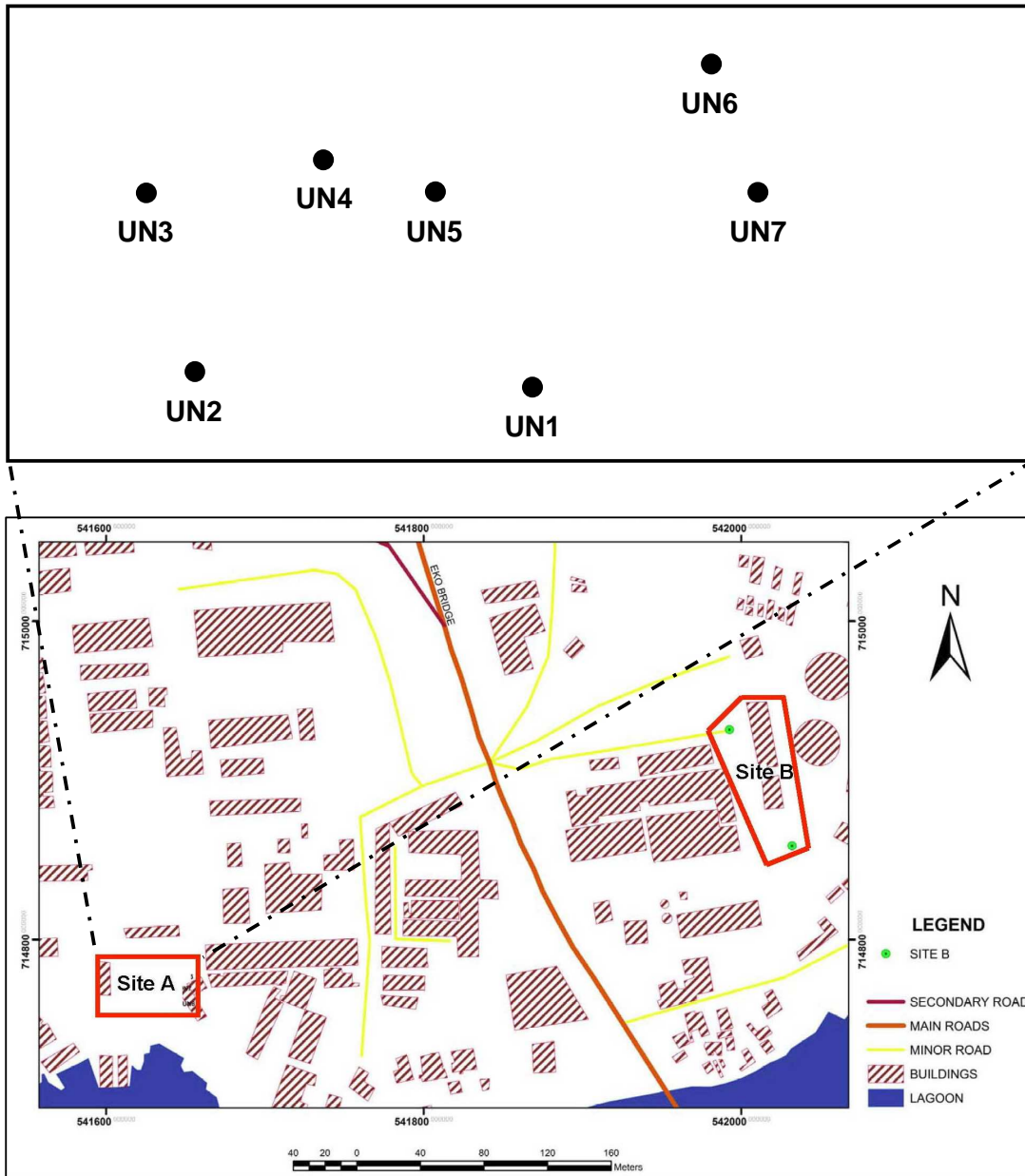
Figure N2.2
Site A – Surface sampling locations in Ijora Power Station, Lagos, Nigeria

The coordinates (as measured with GPS: Mobile Mapper Thales) of the different sampling points in Site A are presented below in Table N2.1. The coordinates of Site B were not taken. The sampling locations for Sites A and B are shown in Figure N2.2.

Table N2.1:
Surface soil samples identity and their coordinates of Site A

Sample ID	Height above sea level (m)	Latitude*	Longitude*
UN1	13	6^0 27. 5749` N	3^0 22. 3543` E
UN2	11	6^0 27. 5835` N	3^0 22. 3456` E
UN3	11	6^0 27. 5874` N	3^0 22. 3451` E
UN4	10	6^0 27. 5877` N	3^0 22. 3478` E
UN5	9	6^0 27. 5873` N	3^0 22. 3510` E
UN6	13	6^0 27. 5889` N	3^0 22. 3576` E
UN7	14	6^0 27. 5870` N	3^0 22. 3571` E

*Coordinates measured by the GIS person from UNILAG

4 INVESTIGATION METHODOLOGY

Sample Collection, Storage and Preservation

Surface soil samples (topsoil) were collected using a clean stainless steel hand trowel and transferred into aluminum foil that had been previously baked in an 150°C oven for 15 hours after rising with organic solvent (pesticide grade acetone). The foil was labelled, sealed, placed in an ice chest cooler and transferred to the laboratory along with the chain of custody documentation. Altogether, 12 soil samples and one oil sample were collected from the station for laboratory analysis. All the sampling points taken on Site A were geo-referenced (using GPS: Mobile Mapper Thales).

The samples were transported to the laboratory in ice chest coolers filled with ice. The samples were allowed to reach room temperature by taking them out of the coolers, and then allowed to stand under ambient conditions in the laboratory for 30 minutes. The extraction of samples started immediately thereafter, followed by gas chromatographic analysis of the sample extracts after sulphuric acid cleanup.

Apparatus Pre-treatment

All glassware used for sample analysis was scrupulously cleaned by soaking it in chromic acid (i.e., 10g $K_2Cr_2O_7$/L of H_2SO_4)[1] overnight, then washed with detergent and copiously rinsed with running tap water followed by distilled water, and then acetone. The glassware was transferred into the oven and dried for two hours at 105°C.

Sample Pre-treatment

Foreign objects such as sticks, leaves, stones, rocks and metals were handpicked from the soil and oil samples, and then each sample was thoroughly mixed with a glass rod to homogenize.

Sample Extraction

The United States Environmental Protection Agency (USEPA, 1996) Validated Method 3540C was followed for the extraction of samples for PCB analysis. Analytical grade

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[1] 1% solution, American Public Health Association [APHA] 20th Edition, pp. 2-77.

reagents and chromatographic grade solvents and adsorbents were used. 30 g of sample was weighed into a 250 mL glass beaker and 50 mL of the extraction solvent (Hexane + Acetone 1:1) was added. The analyte (PCBs) was extracted into the solvent in an ultrasonic bath for three minutes. The extract was filtered using a Gooch crucible and Buckner flask under funnel suction. The extract was collected into a 100 mL quick-fit glass round bottom flask. The extraction was repeated twice and the filtered extracts were pulled together in the quick-fit round bottom flask. The solvent was then evaporated from the extract in a rotary evaporator until the extract was reduced to approximately 2 mL.

Extract Cleanup

The extract was quantitatively transferred into a 15 mL glass centrifuge tube, and 2 mL of concentrated H_2SO_4 was added carefully in a fume hood. The tube was covered and centrifuged for one minute. The phases were allowed to separate for at least a minute. The aqueous layer (H_2SO_4) was removed with a glass Pasteur pipette and the non-aqueous layer (solvent) was then neutralized with 2 mL of 2 M $KHCO_3$. This mixture was centrifuged for one minute. The aqueous layer was carefully removed with the Pasteur pipette after the separation of the liquid layers. The cleanup was repeated until the extract (non-aqueous layer) was colourless. The organic extract was transferred into a calibrated glass centrifuge tube and made up to the original volume (2 mL) with hexane. The cleaned extract was stored in a vial with a PTFE-lined screw-cap, labelled appropriately and analyzed by Gas Chromatography-Mass Spectrometry (GC-MS). The samples were refrigerated after analysis.

PCB Determination by Gas Chromatography–Mass Spectrometry

The concentrations of the PCBs as individual PCB congeners were determined in the extracts using a Shimadzu GC-MS Model QP2010. The gas chromatograph was an open-tubular, capillary column with an electron capture detector (ECD), and the mass spectrometer was used to identify the individual PCB congeners in the extracts.

GC-MS operating conditions

The following GC-MS conditions were used:
- Injector Temperature: 250ºC
- Equilibrium Time : 3 min
- Initial Oven Temperature: 80ºC
- Injection Mode: Split less
- Sampling Time: 1 min
- Flow Control Mode: Linear Velocity
- Pressure: 72.8 kPa
- Total Flow: 30 mL/min
- Purge Flow: 3 mL
- Carrier Gas: Helium
- Column Flow: 1.2 mL/min

Oven Program:

Rate (ºC)	Temperature (ºC)	Hold Time (min)
-	80	1.00
10	180	2.00
10	280	3.00

Total Runtime: 26 min
Column used:
- HP-1MS (Cross linked PH ME siloxane) 19091S-933
  Film thickness: 0.25 μm, Length: 30 m, Column ID: 0.25 mm

MS set-up
- Ion Source Temperature: 200°C
- Interface Temperature: 250°C
- Solvent Cut time: 5 min
- Detector Gain Mode: Relative to Tune Parameter
- Acquisition Mode: SIM (Selected Ion Monitoring)

Calibration Standards

A stock standard containing an equal concentration of Aroclor 1221 and Aroclor 1260 was prepared. Three series of calibration standards were then prepared, containing equal concentrations of both Aroclor 1221 and Aroclor 1260 from the stock standard by diluting with hexane.

Quality Control and Assurance

All glassware was thoroughly cleaned and the use of plastic materials was avoided during sample preparation and analysis. A new set of clean glassware was used for each sample to prevent cross-contamination. A reagent blank was subjected to exactly the same analytical procedure as the samples. All reagents used were of an organic-free grade. A mixture of PCB congeners of known concentrations was also analyzed with the GC-MS. The GC-MS has a detection limit of 0.002 ppm, or 2 ppb.

5   REGULATORY FRAMEWORK

Due to a lack of historical records and national regulations on toxic waste management in Nigeria prior to the Koko toxic dumping incident in 1988, undue misuse of PCB-containing transformer oils is presumed to have occurred at the old power generating station at Ijora. It should be noted that relevant legislation for hazardous waste-oil management (including The Harmful Wastes (Criminal Provisions) Decree No. 42 (FEPA, 1988), and Guidelines and Standards for Environmental Pollution in Nigeria (FEPA, 1991), has only been promulgated since these facilities stopped being used to generate power in 1982. There were no site records to indicate that the agencies that ran the facilities followed any strict legislation or guidelines for the classification, handling of new, or the disposal of used transformer oils; the investigation and determination of the extent of contamination of oil spills; the determination of cleanup strategies; nor the decommissioning of unserviceable transformers at the facilities.

In view of the lack of an appropriate Nigerian national regulatory standard for environmental contamination with PCBs, this PSI Stage 2 assessed PCB concentrations relative to the maximum concentration level of Tables 3.1 and 3.2 of Module 3 (AENV, 2009A).

6   INVESTIGATION RESULTS

Field Observations

The Stage 1 site visits indicated that three major sources of contamination could be expected:
- the PCB-containing transformer oils that were previously used and stored on site, and the empty transformer oil drums that remained on site
- the metal scraps visible at Site A
- the abandoned transformers observed on Sites A and B
.
Consequently, there is a very high potential for the presence of PCBs in all environmental media (i.e., soil, sediment, groundwater, biota, etc.), which are likely to be above most international standards (since no national standard is currently available for this category of contaminants in Nigeria).

Analytical Results

From the seven surficial soil samples at Site A, it was found that two samples, UN6 and UN7, with 139.2 ppm and 132.8 ppm of total PCB concentration respectively, exceeded the Tier 1 Screening Level for PCB-contaminated soils. (Note: 1 mg/kg = 1 ppm). The permissible level for industrial areas, based on the Tier 1 Soil Screening Levels (based on AENV, 2009; see Table 3.1 in Module 3,), is 33 ppm. Thus two samples from Site A exceeded the standard. Table N2.2 shows how the laboratory PCB results compared with the standards. Note that Samples UN6 and UN7, which have concentrations as high as ~139 ppm, were taken from an area of bare land previously used for growing food by employees of PHCN. Figure N2.3 shows the exceedance of the surficial soil concentrations and the corresponding sample locations at Site A.
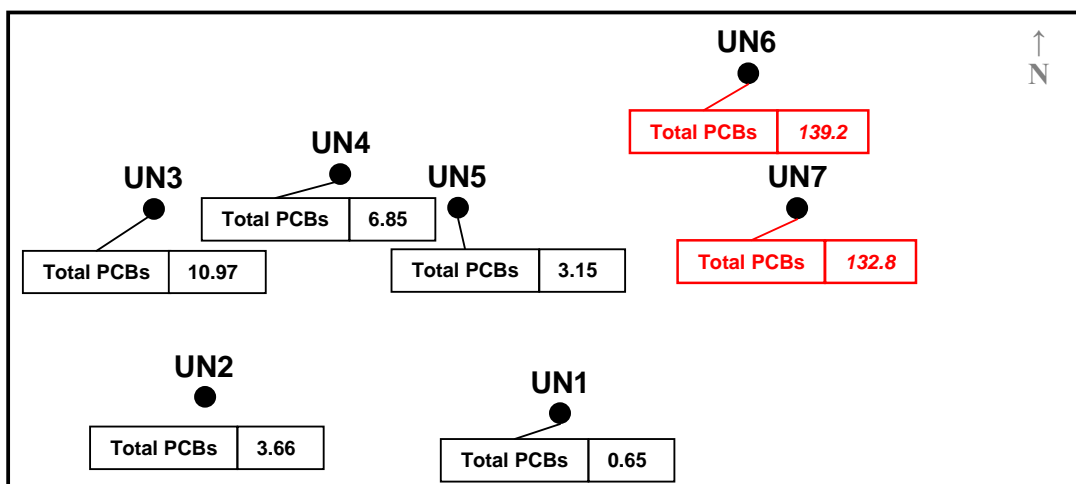
Figure N2.3
Total PCBs concentration in collected surface soil samples in Site A of Ijora Power Station, Lagos

Table N2.2
Site A Surface Soil PCB Analyses and Applicable Standards

Sample ID	PCB concentration (ppm)	AENV 2009 Tier 1 Industrial Soil Levels	
		(ppm)	Contaminated?
UN1	0.65	33	Clean
UN2	3.66	33	Clean
UN3	10.97	33	Clean
UN4	6.85	33	Clean
UN5	3.15	33	Clean
UN6	139.2	33	Contaminated
UN7	132.8	33	Contaminated

In contrast, none of the five surficial soil samples at Site B contained total PCB concentrations above the AENV Tier 1 screening level (see Table N2.3). There are no criteria available for the oil sample taken, but the total PCB concentration in this sample is 253.6 ppm. Since this oil is directly drained to the lagoon, there is great potential for further environmental contamination.

Table N2.3
**Site B Surface Soil and Oil PCB Analysis Results
and Applicable Standards**

Sample ID	PCB concentration (ppm)	AENV 2009 Tier 1 Industrial Soil Levels	
		(ppm)	Contaminated?
UNB1	0.01	33	Clean
UNB2	0.64	33	Clean
UNB3	0.09	33	Clean
UNB4	0.17	33	Clean
UNB5	7.89	33	Clean
UNBO1	253.6	n/a	n/a

6   CONCLUSIONS AND RECOMMENDATIONS

It is likely that the PCB contamination found in soil samples at Site A occurred due to the use of PCB-containing transformer oil during the operation of the old power generating station. The results of the surface soil samples analyzed showed that Site A is contaminated with PCBs, while contamination at Site B is unlikely. PCB concentrations in soil samples at Sites A and B range from 0.65 mg/kg to 139.2 mg/kg, and 0.01 mg/kg to 7.89 mg/kg, respectively. It is therefore recommended that a detailed site investigation be conducted to determine the extent and degree of contamination at Site A.

7   LIMITATIONS OF THE REPORT

Due to budget restrictions, limited samples were collected from Sites A and B during the surface sampling, which was carried out on October 6, 2009. Both the observations and the laboratory analytical results represent only the actual date of sampling. The authors have no responsibility and liability for the results being used in the future; due to the temporal and spatial factors, the extent of contamination would likely be different.

While this investigation solely focuses on PCB contamination, it is highly likely that other contaminants, such as heavy metals, PAHs, and other organic contaminants, are present due to the multiple activities of the site and the surrounding area.

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Preliminary Site Investigation (PSI-S2) Checklist for Nigeria Case Study October 2009

SECTION 2	Preliminary site investigation Stage 2 may include 15–24	Status Y/N
DATA *Goals of the study*	15. Has the investigator discussed the following about the potential contaminants of concern: a) what are the goals of the preliminary site investigation; and b) will analysis of the populations identified in the study lead to achieving these goals?	 Y Y
Populations	16. Does the sampling plan and data: a) adequately identify the contaminants that exist and represent their general distribution; b) establish the physical and chemical controls on contaminant distribution?	 Y Y
Plans	17. Has the investigator: a) explained the rationale behind the sampling plan; b) provided a sampling plan that reflects the potential sources, pathways, and receptors of contaminants; c) over-sampled to compensate invalidated results (broken bags, lost labels, etc.); d) avoided collecting composite samples; e) provided a rationale for using composites or a combination of composite and discrete samples, f) detailed the procedures used to collect, record; confirm and verify the database; g) provided an adequate location for each sample (e.g., has the sample grid been tied into UTM co-ordinates); h) has the investigator attempted to determine the background soil conditions for the parameters being investigated; and i) does the investigator provide a rationale for choosing the area used to represent ambient conditions?	 Y Y N Y N Y Y N Y
	18. If previous studies have been used: a) have the data been summarized and presented in the report; b) have the data been used to add to the density of sampling locations; c) has the source of additional data been identified and its use justified; and d) has the investigator given reasons for including or excluding data from previous studies?	 N N N N
Protocols	19. Have field sampling procedures been carried out according to: a) ministry protocols where available; and b) if modified, presented justification for such modifications?	 N N
	20. Has the investigator: a) included the original quality assurance plan; b) run a complete check of all data against original records; c) provided documentation of the reliability of any data that is significant to the study's conclusions; d) shown that the analytical methods used for all samples conform with methods accepted by ministry recommendations; e) used paired analyses of duplicate samples (where samples are collected separately in the same immediate area); f) used paired analyses of split samples of the same material especially where suspected contaminant levels are believed to be at their highest concentrations; g) discussed the possible reasons for differences between splits and field sample duplicates; h) have recommended ministry lab services QA/QC protocols been followed; and i) documented any corrective action taken if QA/QC reveals significant bias or high imprecision?	 Y N Y Y N N N Y N

EXPLORATORY DATA ANALYSES	21. For univariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; c) made use of graphical representations of the data, such as histograms, or probability plots; d) used summary statistics that describe the centre, location, spread, and shape of the univariate distribution; and e) used logarithmic scaling, if the data are skewed, to make graphical presentations more informative?	Y Y Y Y N
	22. For bivariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; and c) used scatter plots that display the relationship between pairs of variables and linear and rank correlation coefficients that summarize the strength of the relationship?	Y Y N
Outliers	23. For all distributions, has the investigator: a) used rank correlation as an alternative to linear correlation to reduce sensitivity to outliers when summarizing the relationship of two variables; b) used probability plots, scatter plots and data postings to identify outliers; c) determined whether any outliers require that any critical assumptions need to be modified; d) determined the reasons for the existence of the outlier; e) documented the reasons for and provided all relevant information about any outlier value that has been discarded; and f) taken a new sample at a random location within one metre of a discarded outlier sample?	N N N N N N
STATISTICAL ANALYSIS AND INTERPRETATION *Assumptions*	24. Has the investigator: a) described the statistical tools and procedures used to analyze and interpret the data along with their underlying assumptions; b) included calculations and assumptions for population standard deviations estimated for the purposes of a confidence interval calculation; c) provided a rationale for the method used to deal with non-detectable data; d) used a nonparametric alternative as a way of checking the sensitivity of the conclusion to the distribution assumption; and e) included a statement about the uncertainty of all estimated or predicted values?	Y Y N N N
CONCLUSIONS AND RECOMMENDATIONS *Conclusions*	25. Has the investigator: a) identified high risk concerns; b) provided clear and unambiguous conclusions with specific references to the analysis and interpretations that support them; and c) discussed how each conclusion is affected by any underlying assumptions, by the accuracy and precision of the available sample data and by the uncertainty in estimated or predicted values?	Y Y Y
Recommendations	26. Has the investigator: a) provided clear and unambiguous recommendations; b) informed the client of any other issues of potential concern outside of the original goals of the study; and c) provided rationale with any recommendations for further investigation?	Y Y Y
REFERENCES *Complete Information*	27. Has the investigator referenced: a) all data sources, previous studies and other sources (including interviews) that contributed information to the study; and b) any technical literature that provides additional detail on procedures used in the study?	Y Y

APPENDICES QA/QC *Documentation*	28. Has the investigator provided: a) analytical laboratory results, either in printed form or on a diskette (Excel preferred) (mandatory requirement); b) Laboratory QA/QC procedures, sampling protocol and the results of check analyses (mandatory requirement); c) drill logs and test pit logs (mandatory requirement); and d) a site map showing sampling locations? (mandatory requirement – may be included in the main report) 29. Has the investigator included: a) details of statistical computations omitted from the main body of the report; and b) if used, the name and version of the computer software utilized for the data base compilation and the statistical analysis, or a brief description and a reference for any other non-commercial software used in the study?	Y Y Y Y Y Y

Old Power Generating Station, Ijora, Lagos, Nigeria
Detailed Site Investigation

Executive Summary

The PSI Stage 2 concluded that the surface samples taken from Site A, which was established in 1921 and used until 1978, were contaminated by PCBs. Site B, however, commissioned in 1956 for power generation and transmission to Lagos and finally abandoned in 1990, was found to be contaminated to a much lesser extent. Therefore, the determination of the extent and migration of PCBs at Site A was the focus of the detailed site investigation.

Four borehole locations were selected on the basis of the highest PCB concentrations in the surface samples, and the topography of the site. PCB concentrations were found in almost all samples, with only one below detection limit. The PCB contamination and the migration in BHUN 6, 7 and 8 are likely due to the flushing of the transformers and the washing of floors in the repair shop through surface runoff and infiltration to the subsurface soils; whereas BHUN 2 contamination is likely from the cracks of the concrete slab where the transformers are stored, surface runoff and groundwater flow.

Since the groundwater flows toward Lagos Lagoon, further investigation downstream of Site A is recommended to determine the extent of off-site migration. Sediment and benthic samples should be investigated to assess the environmental risk and impact on the Lagos Lagoon, and how this might ultimately affect human health.

1   INTRODUCTION

The typical operational framework for large electric power generation and transmission facilities such as the Ijora station included the use of transformers and capacitors that required oils as coolants and insulating fluids. The results from the PSI Stage 2 revealed that PCB-containing oils, such as Clophen and Askarel, were used to run the transformers at the facility. Consequently, the need to carry out a wider and more detailed study to determine the extent and level of PCB contamination at the station, and the possible pathways beyond the boundaries of the site, necessitated a detailed site investigation. The DSI will principally enable the determination of the extent of PCB contamination, particularly in the soil and water.

2   SITE SYNOPSIS

Site details are available in the accompanying PSI Stage 1 and Stage 2 reports. Based on the PSI, an improved site conceptual model was developed with the focus on exposure and receptors (see Figure N3.1).

Figure N3.1
Exposure Model for Potential Receptors
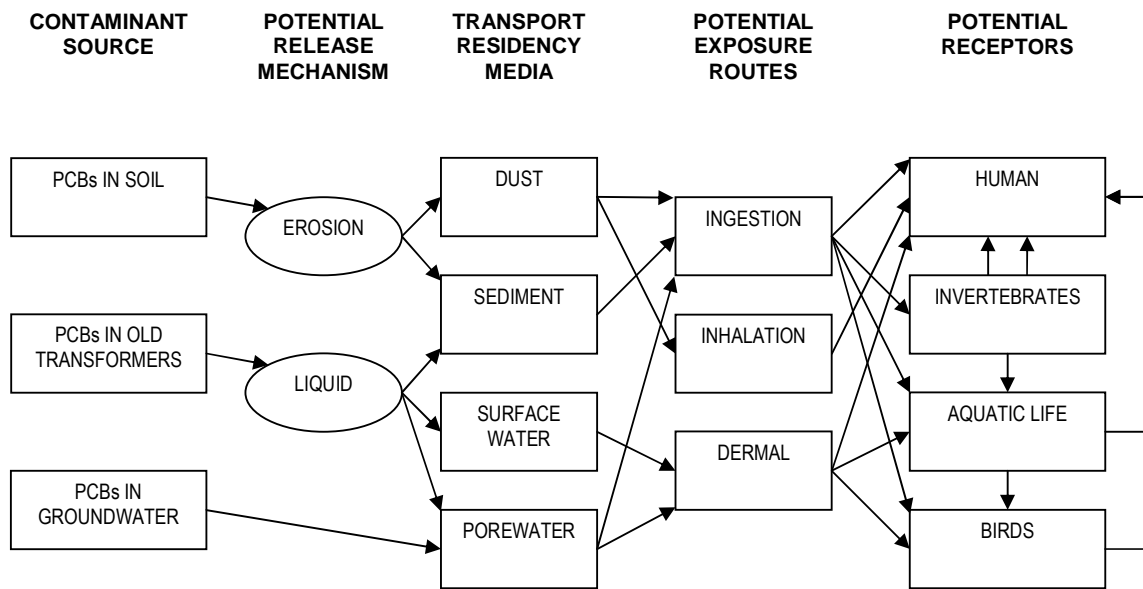
3   INVESTIGATION PLAN

In order to investigate visible spills, as well as those that have already infiltrated the soil, profile/core soil samples will be collected across the study site, and groundwater samples will be collected from strategically located boreholes.   No previously drilled boreholes were available on site. Characteristics of the soil profile for each borehole will be analyzed and the potential pathways for PCBs in groundwater will be investigated.

Sampling Locations

The selection of sampling locations for borehole drilling was based on the PSI Stage 2 surface sample results. Site A was the focus of the DSI because two of its seven surface samples were found to be contaminated by PCBs. Due to the limited budget and time constraints of the DSI, the boreholes had to be completed in two to three days. The four surficial sampling locations that indicated the highest levels of PCB contamination in Stage 2 were selected as surface points to carry out geotechnical boring (boreholes) in order to collect and analyze soil and water samples. This facilitated the determination of the possible extent of contamination within the subsurface soil profile, and also the breached soil horizon(s) that act as pathways for transportation of the potentially contaminated groundwater. The four surface samples from each borehole were used as quality assurance/quality control when compared with the corresponding PSI Stage 2 surface sample results for accuracy. Sampling locations are shown in Figures N3.2 and N3.3.

Figure N3.2
Numbered markers 1-7 in this aerial photograph indicate locations of the surface soil sampling points UN1-7; similarly Nos. 2, and 6-8 are the borehole locations. No surficial sample was picked from location 8.
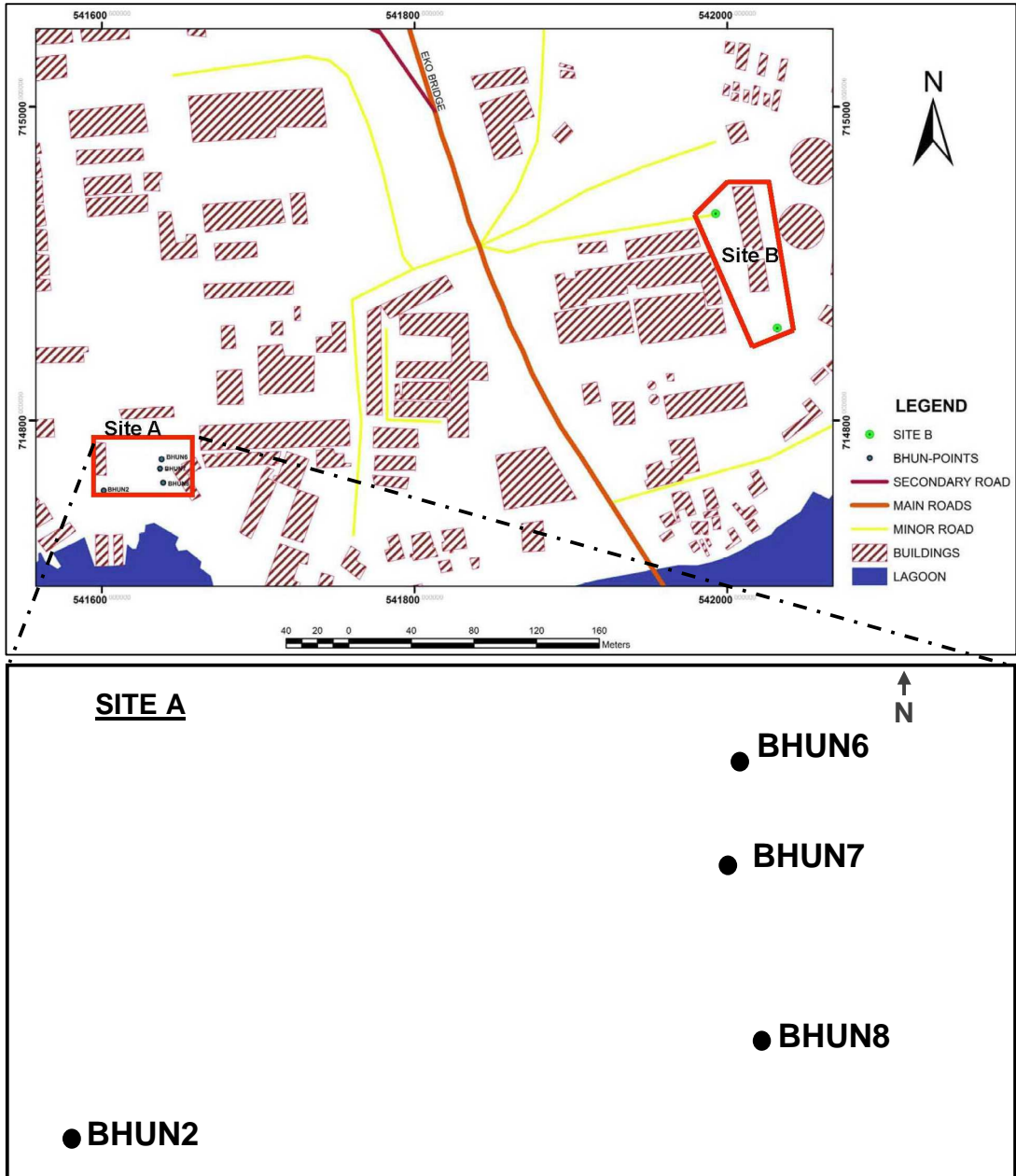
Figure N3.3

Borehole Profile sampling in Site A (Sample ID: BHUN2, 6, 7, 8). The numbering system is the same as surface samples. Note that no beneficial sample was deemed from location 8.

4   INVESTIGATION METHODLOGY

The borehole sampling involved soil boring and the installation of monitoring wells. Four geotechnical boreholes, labelled BHUN2, BHUN6, BHUN7 and BHUN8 (Figure N3.3), were sunk at locations that corresponded with high PCB concentrations from the results of the surficial soil analyses. Three of the four geotechnical boreholes were constructed as groundwater monitoring wells (BHUN2, BHUN 7 and BHUN 8). Grab samples of soil were collected at different depths in the holes for soil profile analysis. USEPA (1994) Validated Method 3540C was used for the extraction of soil samples for PCB analysis. Analytical grade reagents, and chromatographic grade solvents and adsorbents were used. Extraction solvent (Hexane + Acetone 1:1) was used. Gas Chromatograph analysis for PCBs in the soil samples were carried out by Jawura Laboratory Inc. with a Shimadzu GC-MS model QP2010. The GC has an open-tubular, capillary column with an electron capture detector (ECD).

Sample Collection, Storage and Preservation

Details regarding surficial soil sample collection, storage and preservation can be found in PSI Stage 2 report.

Boring was undertaken on October 8-9, 2009 using a shell and auger cable percussion boring technique by means of a Pilcon Wayfarer Rig equipped with the in-situ standard penetration tests (SPT) accessories.

A split-spoon was used to collect the topsoil samples. It was steam-washed and dried both prior to and after each sample collection to avoid cross-contamination. A soil trapper was used for the collection of subsoil samples; it was also steam-washed and dried after use to prevent cross-contamination. No chemicals or drilling fluids, which might have resulted in strata or aquifer contamination, were used during the drilling process.

Borehole diameters varied from 250 mm to 150 mm, depending on the ground conditions. A smaller size was selected where needed to permit the installation of casing to greater depths.

Four boreholes (as labelled with suffix BHUN 2, 6, 7 and 8) were drilled from 0 m to depths of 4.5 m, 5.6 m, 4.5 m and 5.5 m, respectively. The drilling depth for each borehole was chosen to terminate at a significant clay stratum that underlay a sandy rich stratum. It was envisioned that while the sandy stratum would act as a potential pathway for groundwater flow, the underlying clayey stratum would act as a barrier to infiltration, thereby localizing potential contaminants. Samples were collected from 0 m to the final depth at almost regular intervals when no defined soil change boundaries existed. However, where there were noticeable soil type changes, samples were taken at each depth where the soil texture changed.

Soil samples were collected from a 1.5 m split-core. After each use, the core was steam-washed and dried to avoid cross-contamination. The samples were collected from within the central part, which had no contact with the auger. The samples were collected directly into aluminum foil, which had been previously baked in an oven for several hours after rising with an organic solvent. The foil was labelled, sealed, placed in an ice chest cooler and transferred to the laboratory along with the chain of custody documentation immediately after the

sampling. Soil samples were collected from the four boreholes, for geo-environmental laboratory analysis, as follows:

- nine samples from BHUN2
- nine from BHUN6
- seven from BHUN7
- nine from BHUN8

In the laboratory, the samples were refrigerated until extraction commenced.

Soil Sample Analysis

The soil samples were subjected to solvent extraction, and GC-MS analysis of the extracts, to determine the total concentration levels of PCBs, as outlined in PSI Stage 2.

Geotechnical Analysis

No geotechnical information about the site is available. In order to understand ground conditions, such as soil classification, properties and permeability, and groundwater flow directions and rates, geotechnical sampling and testing were conducted in parallel with the environmental sampling. This approach prevented potential cross-contamination and the disruption of the contamination situation before environmental sampling. All boreholes that were not used as groundwater quality monitoring wells were backfilled with bentonite clay to prevent the creation of new PCB migration pathways in the subsurface soil. All water quality monitoring wells were installed according to the standard.[1] The geotechnical data provide the information necessary to interpret PCB migration in the soil and groundwater.

This part of the investigation methodology involved a geotechnical analysis of the soil characteristics to assist with the interpretation of the potential migration pathway for the contaminant. These analyses entailed a detailed assessment of collected soil samples from the four ground borings, BHUN2, BHUN6, BHUN7 and BHUN8, at predetermined depths in both cohesive and cohesion-less strata. The soil test parameters that facilitated the interpretation of fluid ground flow characteristics were carried out at the Civil Engineering Department Laboratory, University of Lagos, Nigeria. These tests included the following:

- particle size distribution test
- natural moisture content analysis
- Atterberg limit test and liquidity index
- void ratio, porosity and bulk unit weight
- permeability test

The results of the geotechnical report have been used to interpret the migration of PCBs in the subsurface of the site and their potential migration to the surrounding environment.

Groundwater Analysis

Three out of the four boreholes (BHUN2, BHUN7 and BHUN8) were installed as groundwater monitoring wells after soil samples had been collected for environmental and

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[1] Barcelona et al. (1985) Illinois State Water Survey

geotechnical analyses. Groundwater sampling was carried out on November 23, December 1 and December 15, 2009.

Water samples were collected with the aid of an electric pump. The pumping test was carried out for the duration of 20 minutes for each well with a ¾ HP submersible pump. The pumping was monitored until it became stable with a discharge of 500 mL for three seconds, which is equivalent to a pumping rate of 166.7 ml per second, to ensure that the water sample collected reflected the groundwater quality, rather than the stagnant water. Water samples were then collected in 500 mL amber glass bottles. Each bottle was sealed, labelled and placed in an ice chest cooler before it was transferred to the Jawura Analytical Laboratory in Lagos with its chain of custody documentation for further processing.

Glassware used for the water sample analysis was scrupulously cleaned by soaking it in chromic acid overnight, washing it with detergent, then copiously rinsing it with running tap water followed by distilled water, and then acetone. The glassware was transferred into the oven to dry for two hours at 105°C.

The USEPA Validated Method 3540C was used for the extraction of samples. Analytical grade reagents and chromatographic grade solvents were used.

100 mL of sample was measured into a 500 mL separating glass funnel, and 100 mL of the extraction solvent (Dichloromethane) was added. The content was shaken vigorously to transfer the analyte into the extracting solvent. The non-aqueous layer (dichloromethane containing the analyte) was transferred carefully and filtered into a 250 mL quick-fit round bottom glass flask. The extraction was repeated twice and the filtered extracts were pulled together in the quick-fit round bottom flask. The solvent was evaporated in the rotary evaporator until the extract was reduced to approximately 2 mL.

The concentrations of the individual PCB congeners were determined in the extracts with a Shimadzu GC-MS model QP2010.

Quality Control and Assurance

All glassware was thoroughly cleaned and the use of plastic materials was avoided during the sample collection, treatment, extraction and analysis steps. A new set of clean glassware was used for each sample to prevent cross-contamination. A reagent blank was subjected to exactly the same analytical procedure as the samples. All reagents used were of organic-free grade.

Determination of Groundwater Flow Direction

The direction of groundwater movement was determined based on the three monitoring boreholes, BHUN2, BHUN7 and BHUN8. Groundwater moves from areas of high hydraulic gradient to areas of lower hydraulic gradient with the direction essentially perpendicular to the equipotential lines (USEPA, 1994; Abam TSK, 2004).

5   REGULATORY FRAMEWORK

See PSI Stage 2 for details about the regulatory framework. In view of the lack of appropriate Nigerian national regulatory standards for PCBs in the environment, we have adopted the Tier 1 Screening Level of Tables 3.1 and 3.2 of Module 3 (AENV, 1009a) to identify if the site is contaminated with PCBs and if there is risk.

6   INVESTIGATION RESULTS

Soil Profile

The results of geotechnical investigations of the site showed that the general stratigraphy of the subsurface deposits observed from borehole logs can be classified into three zones, as shown in Table N3.1.

Table N3.1
General Description of Soil Profiles of Study Location

Zone	Depth (m)	Soil Description
1	0 – 4.00	Darkish grey/reddish brown to grayish brown lateritic sandy silty clay interspersed with a band of silty clay to silty sandy clay, particularly at the topmost layer of BHUN8 of the zone being identified with occasional concretionary gravel in places
2	4.00 –5.25	Grayish/grayish brown to yellowish brown fine medium-grained sand ranging from 4.00 - 5.25 m with traces of clay in places, except in BHUN2 where we identified the layer between 2.48 m and 4.00 m
3	5.25 - 5.80	Grayish/darkish brown to yellowish brown sandy silty clay mixed with silty clay in BHUN2 and BHUN8, except in BHUN2 where we identified the layer between 4.00 m and 5.00 m

Extent of PCB Contamination in Soil

Table N3.2 summarizes the PCB analytical results with the PCB concentrations that exceed the Tier 1 Screening Level (see Table 3.2 in Module 3) highlighted in red.

The major areas of high PCB concentration level within each soil profile include the following:
- BHUN2 showed contamination only within the middle of the soil profile, at about 2.4 m.
- BHUN6 had values exceeding regulatory limits within the soil profile, at 0 m to 0.35 m.
- BHUN7 showed contamination within two sections of the soil profile, with higher contaminated horizon, at 0 m to 0.25 m and 3.0 m to 4.0 m, respectively.
- BHUN8 also showed contamination within two sections of the soil profile, with a much the highest contaminated horizon only within the top horizons, at 0 to 0.35 m and to 0.8 to 1.0 m.

Table N3.2

Borehole Soil Profiles and Results of PCB Analyses and the Applicable Standard (Table 3.1 of Module 3)

Sample ID	Depth (m)	PCB concentration (mg/kg)	Applicable Standard (mg/kg)	Exceeded??
BHUN2	0-0.25	3.63	33	Clean
	0.25-1	0.32	33	Clean
	2.0	2.73	33	Clean
	2.29	25.1	33	Clean
	2.4	**154**	33	**Contaminated**
	2.48	BDL	33	Clean
	3.0	3.69	33	Clean
	4.0	15.7	33	Clean
	4.4-4.5	12.1	33	Clean
BHUN6	**0-0.35**	**48.7**	33	**Contaminated**
	0.8-1.0	29.6	33	Clean
	1.5-1.8	1.32	33	Clean
	2.0-2.3	2.49	33	Clean
	2.5-3.0	6.91	33	Clean
	3.0-4.0	6.28	33	Clean
	4.0-4.5	5.69	33	Clean
	4.5-5.2	15.9	33	Clean
	5.25-5.6	25.9	33	Clean
BHUN7	**0-0.25**	**45.8**	33	**Contaminated**
	0.8-1.0	0.95	33	Clean
	1.5-1.8	5.00	33	Clean
	2.0-2.3	5.12	33	Clean
	2.5-3.0	2.38	33	Clean
	3.0-4.0	**35.0**	33	**Contaminated**
	4.0-4.5	19.2	33	Clean
BHUN8	**0-0.35**	**195.0**	33	**Contaminated**
	0.8-1.0	**273.0**	33	**Contaminated**
	1.5-1.8	9.42	33	Clean
	2.0-2.3	8.74	33	Clean
	2.5-3.0	2.15	33	Clean
	3.0-4.0	4.42	33	Clean
	4.0-4.5	8.52	33	Clean
	4.5-5.0	14.4	33	Clean
	5.0-5.5	13.5	33	Clean

BDL = Below Detection Limit (< 2 ppb)

The surface points and subsurface profiles where samples exceeded the PCB criteria are presented in Figure N3.4.
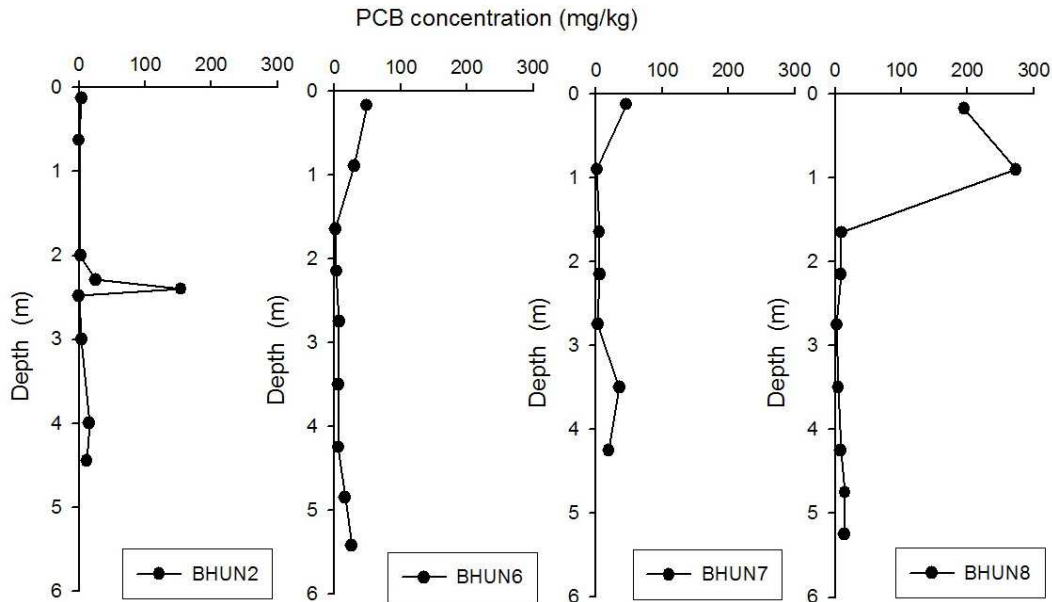
Figure N3.4
PCB contamination profiles for boreholes BHUN2, BHUN6, BHUN7 and BHUN8.

The general horizons where PCB-contaminated soil was found (as shown in Table N3.2), when interpreted with the subsoil texture analysis in Table N3.1, show that the PCBs are localized more within the sandy strata that overlies the clayey strata. This might be because the lower clay horizons have acted as a barrier to infiltration. The sandy rich horizons are envisioned to act as pathways for groundwater flow due to relatively high porosity and permeability compared with the clayey rich horizons.

Groundwater Quality

The PCB concentrations in the groundwater samples that were collected from three monitoring wells were compared to the AENV (2009) standard (see Table 3.2 of Module 3 for industrial groundwater of 0.0094 mg/L). All samples collected during the period, November 11-December 12, 2009, have PCB concentrations that exceed the maximum contaminated limit for groundwater (see Table N3.3). PCB concentrations are in the order of a thousand times greater than the AENV standard.

Table N3.3
Results of PCB Analyses of Borehole Water and the Applicable Standard (Table 3.2 of Module 3)

Borehole ID/ Static Water Level (m)	Sampling Date	PCB Concentration (mg/L)	Applicable Standard (mg/L)	Exceeded?
UNBH2/ 2.43	23/11/2009	50.20	0.0094	Contaminated
	01/12/2009	57.84	0.0094	Contaminated
	15/12/2009	48.40	0.0094	Contaminated
UNBH7/ 1.30	23/11/2009	38.40	0.0094	Contaminated
	01/12/2009	53.95	0.0094	Contaminated
	15/12/2009	59.20	0.0094	Contaminated
UNBH8/ 2.60	23/11/2009	66.30	0.0094	Contaminated
	01/12/2009	54.00	0.0094	Contaminated
	15/12/2009	41.30	0.0094	Contaminated

Groundwater Flow Direction

The static water level for the three boreholes ranges from 1.3 m to 2.6 m, implying that groundwater is close to the ground surface and therefore can very easily be contaminated. Furthermore, this proximity of the groundwater to the surface implies that very little natural screening by the overlying soil strata is possible before the potential contaminants breach the groundwater aquifer, which flows in an N-S direction, as shown in Figure N3.5 (contour lines or equipotential lines were plotted from the reduced water levels of the three monitoring boreholes, with the direction of the groundwater movement essentially perpendicular to the equipotential lines; USEPA, 1994; Abam TSK, 2004). The NE-SW groundwater flow pattern across the study site is towards the direction of the Lagos Lagoon.

Figure N3.5
Groundwater flow direction in Site A. The arrow is pointing to North direction
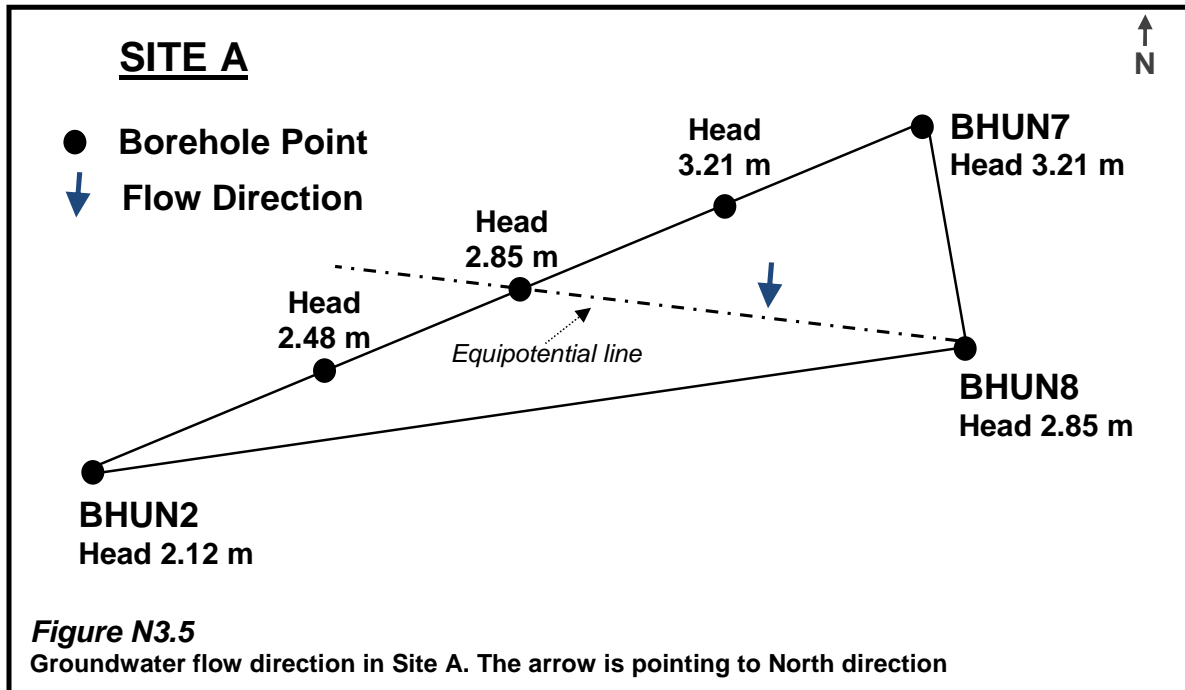
Contaminant Migration in Soil

Figure N3.6 shows a cross-section of the soil profile with correlation of the sandy rich horizon across the boreholes as pathways for contaminated groundwater plumes for the breached strata.
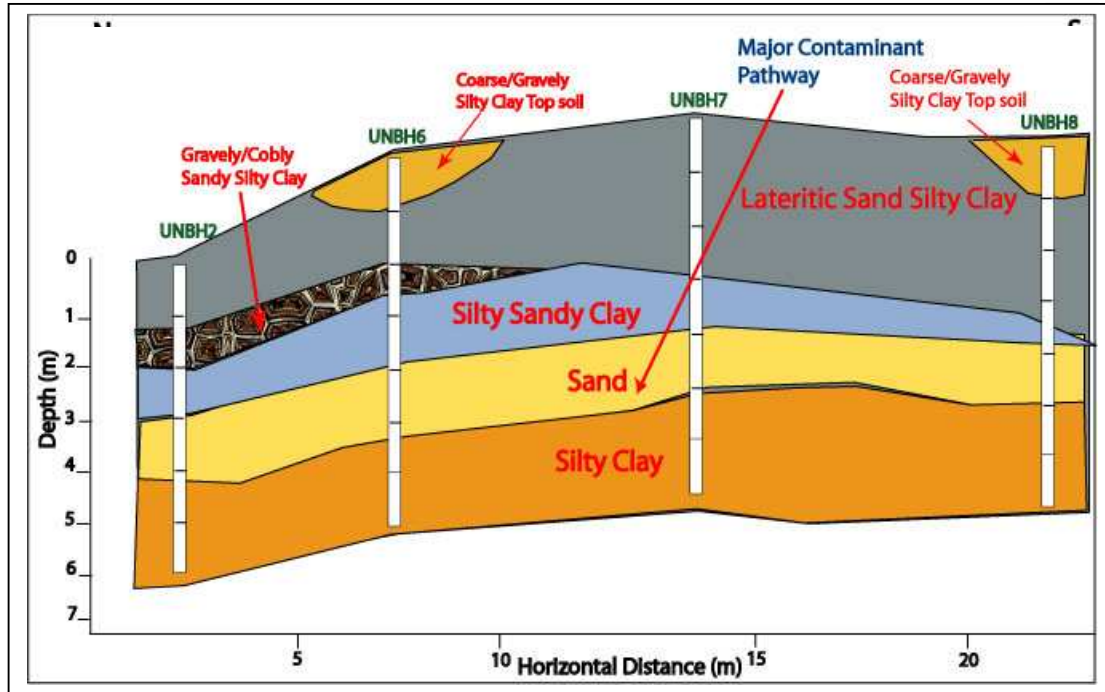
Figure N3.6
Correlation of soil horizons across boreholes showing potential pathway for contaminated groundwater

Since there is a significant residential community and continued use/activity around Site A, there may be groundwater wells within the surroundings that are used for domestic purposes. Consequently, the contamination status of the subsoil as a pathway for groundwater flow was analyzed at four boreholes, which are indicated in Figure N3.6. A total of 34 subsoil samples were collected and analyzed for PCBs, and the results indicated that 26 samples exceeded the criteria for contamination, as shown in Table N3.2.

7   CONCLUSION

From the analyses of soil and water media carried out in this investigation, the surficial soil results for Sites A and B showed that only two out of the seven sampling points indicated PCB levels beyond the maximum contamination limits. Subsoil samples taken from the four boreholes also showed evidence of contamination. Interestingly, the borehole PCB contamination was stratified, which may have been influenced by the subsurface soil profile. Consequently, the groundwater analyzed from three of the four boreholes showed very high concentrations of PCBs beyond the maximum contamination limits for groundwater. The observed groundwater flow direction in this investigation is from N to S, and implies that runoff will ultimately impact the Lagos Lagoon, which is approximately 10 m from the site.

It is envisioned that any domestic groundwater wells in the immediate vicinity of the site will also have elevated concentrations of PCBs and PAHs based on these results.

The DSI has confirmed the findings of the PSI Stage 1 and Stage 2 reports. The DSI has also shown that it is likely that the power generating operations that used PCB-containing oils, as well as the old and abandoned transformers, empty oil drums and waste oil at Sites A and B, have contaminated the study site with PCBs.

Finally, the DSI has confirmed the suspicion that the spills of used oil on the ground, particularly around the repair workshop area in Site A, have caused migration of PCBs and PAHs into the subsurface soils and groundwater of the surrounding area through runoff and infiltration. This is exacerbated by the high total annual rainfall in the area, of about 1,831.5 mm.

8   RECOMMENDATIONS

It is recommended that continued sampling and analysis of the boreholes and artesian wells in the immediate vicinity of the study site be carried out systematically.

Overall, remediation of the station is highly recommended due to the active and ongoing land use in the area and the great number of people living and working in the vicinity of the site. A site management and remediation strategy is needed to protect human health.

Both the channel from the repair workshop on Site A, and the open drainage system that traverses the site, discharge directly into the Lagos Lagoon. It is therefore recommended that further study of the extent of contamination of the lagoon by PCBs, and other likely contaminants such as PAHs and heavy metals, be carried out. This study should focus, in particular, on the bottom sediments of the lagoon in the areas adjacent and downstream to the study site.

As Site B is currently partly used for some domestic farming, bioaccumulation studies of PCBs and PAHs in the biota around Site B are recommended in order to advise on the extent of the danger posed by food products from the site prior to its remediation. In the meantime, farming should be discontinued at the site, and domestic produce from the site should not be consumed.

9   LIMITATIONS OF THE REPORT

This work has been conducted for training purposes with significant time and budget restraints. Although the participants have followed the procedures outlined in Module 2, it is likely that cross-contamination has occurred due to the obsolete sampling equipments and inadequate accessories. In addition, the constant power failures in Lagos and the lack of low temperature freezers might also have affected the analytical results.

The analytical results in this report only reflect the times and dates of the sampling period. The use of these results at anytime in the future might be incorrect as the input of PCBs and their migration continues.

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Detailed Site Investigation Checklist for Nigeria Case Study
October 2009

A.) REQUIRED MATERIALS			
Personal Protection Equipment	OK	NA	Units
• Chemical protective clothing category III for high risk	OK		
• Fall protection equipment		NA	
• Reflecting vest and/or other visibility reflecting accessories		NA	
• Face masks		NA	
• Full face mask respirator and mask filters (against organic vapours and toxic particles)		NA	
• Safety helmet		NA	
• Shatterproof safety glasses	OK		
• Hearing protection	OK		
• Work gloves and single-use nitrile gloves	OK		
• Safety boots		NA	
• Overshoes/Overboots	OK		
Collective protection equipment	OK	NA	Units
• First aid kit		NA	
• Emergency showers		NA	
• Eye wash cleaning water		NA	
• Autonomous oxygen supply		NA	
• Fire extinguisher		NA	
• Detection devices (for fumes, gases, etc.)		NA	
• Absorbent paper		NA	
Drilling machine	OK	NA	Units
• Drill pipes	OK		2
• Drill crowns	OK		
• PVC pipe	OK		
• Slotted pipe	OK		
• Stopper	OK		
• Pipe cap	OK		
• Gravel		NA	
• Cement	OK		2
• Bentonite	OK		2
• Cover	OK		4
Equipment for soil-gas, hydraulic conductivity and sampling activities	OK	NA	Units
• Hand auger equipment		NA	
• PID (Photoionization detector)		NA	
• Teflon tube		NA	
• Freezing bags	OK		
• Explosimeter		NA	
• pH meter		NA	
• Conductivity and temperature meter		NA	
• Redox meter		NA	
• Dissolved oxygen meter I		NA	
• Interphase probe		NA	
• Bailers (minibailers)		NA	
• Pumps (minipurgers)	OK		1
• Cool boxes	OK		2
• Soil sample bags	OK		100
• Water sample bottles (containers)	OK		12
• Adhesive labels for sample bags	OK		
Geophysical works	OK	NA	Units
• Geophysical gear		NA	

	OK	NA	Units
• Laptop and its charger		NA	
• Data registry and storage system		NA	
• Extension cord		NA	
• Adapters		NA	
• Wire coils		NA	
• Network cable		NA	
• Probe or small measurement device	OK		2
• Electric winch		NA	
• Junction cable between probe and data registry/storage equipment		NA	
• Voltmeter to check connections		NA	
Other materials	OK	NA	Units
• Toolbox	OK		
• Geological hammer	OK		
• Allen wrench		NA	
• Screwdrivers		NA	
• Mallet		NA	
• Pliers		NA	
• Compass/GPS (Geographical Positioning System)	OK		2
• Spray or paint for marking		NA	
• Insulating tape		NA	
• Packaging tape		NA	
• Tape measure	OK		
• Photo camera	OK		
• Notebook & pen	OK		
• Edding		NA	
• Cutter		NA	
• Scissors		NA	
• Penknife		NA	
• String	OK		
• Lantern		NA	

B.)	HEALTH AND SAFETY MEASURES	OK	NA
•	Is there an approved Health and Safety Plan?	OK	
•	Has every member of the team been instructed about the Health and Safety Plan?	OK	
•	Have affected people/organizations been warned about the works?		NA
•	Can all the Health and Safety Plan requirements be fulfilled?	OK	
C.)	ENVIRONMENTAL SITE ASSESSMENT		
	C.1.) Soil gas analysis	OK	NA
•	Performance of a utility survey	OK	
•	Determination of distribution of soil gas investigation points		NA
•	Determination of sampling depth	OK	
•	Pre-drilling	OK	
•	Drilling of boreholes	OK	
•	Soil gas sample collection		NA
•	Field analysis of soil gas samples		NA
•	Laboratory analysis of soil gas samples		NA
	C.2.) Application of geophysical methods	OK	NA
•	Design for establishing the position of soil profiles to be analyzed	OK	
•	Determination of direction and length of soil profiles to be analyzed	OK	
•	Determination of number of soil profiles to be analyzed	OK	
•	Determination of separation between soil profiles to be analyzed	OK	
•	Determination of separation between measurement points	OK	
•	Taking measurements	OK	
	C.3.) Drilling of soil borings	OK	NA
•	Location of soil borings	OK	
•	Design of soil borings distribution in the study area	OK	
•	Sign exact sampling points with painting/spray		NA
•	Execution of soil borings (for each drilling location)	OK	
•	Performance of utility survey	OK	
•	Drilling of localization soil borings (3-4 m depth)	OK	
•	Drilling of investigation soil borings (more than 4-5 m depth)	OK	
•	Filling of each hole with grout to ground surface after conclusion of each soil boring		NA
Collection of the following information during drilling works			
•	Name or identification number of soil boring	OK	
•	Start and end date of works	OK	
•	Observed lithology		NA
•	Soil appearance and colour	OK	
•	Presence of humidity		NA
•	Water levels and non-aqueous phase liquid levels	OK	
•	Drilling company	OK	
•	Drilling typology	OK	
•	Boring depth	OK	
•	Drilling device diameter	OK	
•	Collected samples, with relative sampling depth and identification code	OK	
•	Stratigraphy, with possible visual exam notes	OK	
•	Taking photographs of samples and sample locations	OK	

	OK	NA
C.4.) Installation of monitoring wells	**OK**	**NA**
• Completion of strategic investigation soil borings as monitoring wells installing piezometers	**OK**	
• Well development and purging until the water runs clear and physicochemical parameters are stable	**OK**	
Measurement of the following parameters prior, during and after well development		
• Static water level	**OK**	
• Groundwater presence and level	**OK**	
• Water colour	**OK**	
• Turbidity		**NA**
• Odour		**NA**
• pH		**NA**
• Temperature		**NA**
• Specific conductance		**NA**
• Presence of non-aqueous phase liquid (NAPL)		**NA**
Recording of data related to well installation activities, specifying:		
– Piezometer identification number		**NA**
– Measurement data	**OK**	
– Piezometer depth		**NA**
– Piezometer location coordinates		**NA**
– Supervision of monitoring well installations by specialists	**OK**	
C.5.) Topographic survey	**OK**	**NA**
• Measurement of X,Y,Z coordinates of each soil borehole, groundwater monitoring well and trial pit by means of a GPS	**OK**	
C.6.) Hydraulic conductivity tests	**OK**	**NA**
• Performance of slug tests, either adding or removing a measured quantity of water from monitoring wells		**NA**
• Rapid water-level measurements at regular time intervals	**OK**	
C.7.) Sampling activities	**OK**	**NA**
Soil sampling:		
• Extraction of soil core samples and placement in core boxes	**OK**	
• Checking for the presence of any visual of olfactory evidence of contamination during drilling operation	**OK**	
• Use of PID (Photoionization Detector) for rapid field sample analysis		**NA**
• Correct classification of soil samples taking into account parameters as soil type, colour, grain size distribution, textural changes, etc	**OK**	
• Selection of representative samples	**OK**	
• Soil sample preparation and placement into containers	**OK**	
• Labelling of soil sample containers	**OK**	
• Storage of soil sample containers at low temperatures (4ºC) and in the dark	**OK**	
• Sending of soil sample containers in refrigerated or thermo-insulated boxes to the laboratory in 24-48 hours	**OK**	
• Completion of Chain of Custody including for each sample the same information reported on its label	**OK**	
• Taking photographs at sampling locations and of soil samples	**OK**	
Groundwater sampling:		
• Collection of groundwater samples from monitoring wells after well development		**NA**
• Collection of water samples directly into appropriate containers		**NA**
• Labelling of water sample containers		**NA**
• Storage of water samples at low temperatures (4ºC) and in the dark		**NA**
• Sending of water samples to the laboratory in refrigerated or thermo-insulated boxes in 24-48 hours		**NA**
• Taking photographs at sampling locations and of water samples		**NA**

D.) ENVIRONMENTAL SITE MONITORING IN THE FIELD		
Groundwater contamination control through monitoring wells:	**OK**	**NA**
• Design of a strategic monitoring network: determination of optimal location and number of piezometers		**NA**
• Design of a monitoring program, including:		
– Frequency of groundwater level measurements	**OK**	
– Frequency of groundwater sample collection		**NA**
– Water sample analysis types		

Detailed Site Investigation Checklist for Nigeria Case Study
October 2009

Section	Checklist	Status Yes/No (Y/N)
SUMMARY *Important information*	1. Does the investigator: a) identify who the major participants are in the investigation; b) provide important facts and study results at the beginning of the report; c) provide a clear understanding of the data contained within the body of the report; and d) discuss the results of any preliminary site investigations?	Y Y Y Y
Sampling information	2. Does the summary: a) state how representative the sampling pattern and analysis is of property soil conditions; b) specify the probabilities of false positive and false negative answers; c) identify what the chemical analysis program focused on; and d) indicate how reliable the sampling methodology and laboratory analysis was?	Y N Y Y
OBJECTIVES *Goals*	3. Are the goals of the investigation: a) clearly stated; b) in compliance with the scope of work agreed upon with the client; and c) consistent with ministry goals and objectives?	Y Y Y
SITE HISTORY & DESCRIPTION *Description of the site*	4. Has the investigator: a) specified the dates when site visits were conducted; . b) provided a site map, including land use, relevant buildings found on site, dimensions in metres and area of the property in hectares; c) included natural features such as lakes, rivers, streams found at least partially within the boundaries of the property; d) included constructed features such as, underground storage tanks, lagoons, ditches, sumps within buildings, and waste storage areas; e) provided a reasonable substitute if no site map is available; f) provided an area topographic map of 1: 20 000 or larger; and g) included a scaled aerial photograph of the site and adjacent environs?	Y Y Y Y N Y Y
Climatic conditions	5. For DSIs are: a) annual precipitation records provided; b) along with a description of seasonal variations in precipitation; and c) estimates of infiltration rates provided?	Y Y Y
Groundwater	6. Has: a) the depth to groundwater from the ground surface and the depth and thickness of multiple aquifers been calculated; b) seasonal groundwater fluctuation been documented; c) the lithology and vertical permeability of the unsaturated zone been described; and d) the stratigraphy, structure, geometry, porosity, hydraulic conductivity, storage properties, transmissivity, and groundwater flow direction of the saturated zone been described?	NA NA NA NA
Wells	7. If monitoring wells have been installed near the disposal areas previous to this investigation, a) have the monitoring results been reviewed; b) have data been included that indicate why and when a monitoring well was installed and by whom; and c) has any previous geotechnical investigative work been identified and reviewed?	 N N N

Soil types and soil depths	8. Has the investigator: a) provided soil survey information at a scale of 1:20 000 or larger; b) contacted soil survey personnel, or local soil scientists; c) provided an on-site map and appropriate cross-sections showing soil types, soil depth and other soil parameters that may be related to location and extent of contaminants; and d) shown the relationship between groundwater and soil in the cross-sections?	Y Y Y Y
Basic preliminary information about liability	9. Does the investigator: a) provide adequate information about any court or administrative actions, ministry orders, Federal charges under the _Fisheries Act_ etc., orders; and b) surmise whether there will be any potential litigation in this case?	N N
DATA _Goals of the study_	10. Has the investigator discussed the following about the goals of the study: a) what are the goals of the detailed site investigation; b) will analysis of the populations identified in the study lead to achieving these goals; and c) are the goals extensive enough to identify the Area(s) of Environmental Concern (AEC)?	Y Y Y
Populations	11. For detailed site investigations has the investigator: a) used historical and other preliminary site investigation information to help delineate separate populations; b) attempted to identify how many contaminant distributions there are; and c) attempted to identify background levels in the surrounding area for contaminants that occur naturally or that may have been deposited by non-point sources?	Y Y Y
Plans	12. For detailed site investigations: a) does the investigator explain the rationale behind the sampling plan; b) does the sampling plan reflect the potential sources, pathways, and receptors of contaminants; c) does the plan reduce the potential of type I and type II errors; d) has the investigator over-sampled to compensate for invalidated results (broken bags, lost labels, etc.); e) has the investigator avoided collecting composite samples for preliminary site investigations; f) has the investigator provided a rationale for using composites or a combination of composite and discrete samples; g) has the investigator detailed the procedures used to collect, record, confirm and verify the database; h) does the investigator provide an adequate location of each sample (e.g., has the sample grid been tied into UTM co-ordinates); i) has the investigator determined the background soil conditions for the parameters being investigated; and j) does the investigator provide a rationale for choosing the area used to represent ambient conditions?	Y Y Y N Y Y Y Y Y Y

	13. If previous studies have been used in the detailed site investigation: a) have the data been summarized and presented in the report; b) have the data been used to add to the density of sampling locations; c) has the source of additional data been identified and its use justified; and d) has the investigator given reasons for including or excluding data from previous studies?	N N N N
	14. Has the investigator: a) used a regular grid with a randomly located origin to estimate contaminant distribution in non-areas of environmental concern (non-AECs); b) collected the number of samples needed to conform with the level of confidence require to establish contaminant levels in non-AECs; and c) used the coefficient of variation to determine if non-AECs have been unaffected by local AECs?	Y Y Y
	15. For the sampling plan has the investigator: a) oriented the sample grid in the direction (if known) of flow of the pollutant, which may relate to site topography or wind direction; b) selected random samples, locations and/or starting points using procedures based on uniform random numbers; and c) included a random number table?	Y Y N
	16. For the detailed site investigation of stockpiles has the investigator: a) designed a sampling program that ensures a fair representation of the contaminant concentrations in the entire pile; b) based the stockpile classification on at least five separate analyses; and c) determined if the material within the pile is sufficiently homogenous to warrant classifying the entire under a single classification?	Y Y Y
	17. For investigations of groundwater: a) has the investigator used any groundwater data available from preliminary site investigations; b) have at least 3 monitoring wells been used with at least one located up-gradient of groundwater flow; .. c) have samples been collected at least 24 hours after the development of a well; d) have groundwater samples been collected after wells have been purged; and e) has integrity testing of underground storage tanks near sensitive receptors such as potable water supplies been carried out?	N Y N Y N

Protocol	18.	Has the investigator: a) included the original quality assurance plan; b) run a complete check of all data against original records; c) provided documentation of reliability of any data that is significant to the study's conclusions; d) shown that no systematic bias has been used during the sampling procedure, including collection, preparation and analysis; e) shown that the analytical methods used for all samples are acceptable to the ministry; f) used control charts to monitor and control the accuracy and precision of the analyses for large studies with more than 100 samples; g) used a t-test to determine whether the average of repeat analyses is significantly different from the established reference value; h) used paired analyses of duplicates of the same material especially where suspected contaminant levels are believed to be at their highest concentrations; i) shown that paired analyses of sample material split in the field shows a rank and linear correlation of 0.95 or greater for metallic and inorganic contaminants, and 0.90 or greater for organic contaminants; j) followed recommended ministry lab services QA/QC protocols; and k) documented any corrective action taken if QA/QC reveals significant bias or high imprecision?	Y Y Y Y Y N N N N Y Y
	19.	For AECs: a) has the investigator ensured that the spacing between samples is smaller than the range of correlation; and b) has the investigator used multi-stage sampling plans to detect and identify the extent of hot spots, including fine grids and step-outs?	Y Y
EXPLORATORY DATA ANALYSES *Non-parametric method*	20.	For detailed site investigations, has the investigator: a) made all distribution assumptions explicit in the report; b) used non-parametric methods to show data that is not normally distributed; c) used percentile-based statistics, such as quartiles and the median, to supplement the more traditional mean and standard deviation; and d) used box plots as an alternative to histograms especially when comparing two or more groups of data?	Y Y N N
Univariate descriptions	21.	For univariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; c) made use of graphical representations of the data, such as histograms, or probability plots; d) used summary statistics that describe the centre, location, spread, and shape of the univariate distribution; and e) used logarithmic scaling, if the data are skewed, to make graphical presentations more informative?	Y Y Y Y N
Bivariate Descriptions	22.	For bivariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; and c) used scatter plots that display the relationship between pairs of variables and linear and rank correlation coefficients that summarize the strength of the relationship?	Y Y N

Spatial Description	23.	Has the investigator used: a) contour maps and cross-sections to show spatial distribution of contaminants;	Y
		b) graphical displays that present the available data in their spatial context;	Y
		c) sample values for data on maps or cross-sections;	Y
		d) colours, grey scales, or symbols to high-light the locations of the highest sample values;	Y
		e) kriging for the purpose of interpolation and not extrapolation; and	N
		f) quadrants or other forms of local statistics to assist the reader in understanding and evaluating decisions about statistical populations and trends?	N
Outliers	24.	For all distributions has the investigator: a) used rank correlation as an alternative to linear correlation to reduce sensitivity to outliers when summarizing the relationship between two variables;	N
		b) used probability plots, scatter plots and data postings to identify outliers;	N
		c) determined whether the existence of outliers requires that any critical assumptions need to be modified;	N
		d) determined the reasons for the existence of the outlier;	N
		e) documented the reasons for and provided all relevant information about any outlier value that has been discarded; and	N
		f) taken a new sample at a random location within one metre of a discarded outlier sample?	N
STATISTICAL ANALYSIS AND INTERPRETATION *Assumptions*	25.	Has the investigator a) described the statistical tools and procedures used to analyze and interpret the data along with their underlying assumptions;	N
		b) included calculations and assumptions for population standard deviations estimated for the purposes of a confidence interval calculation;	N
		c) provided rationale for method used to deal with non-detectable data;	Y
		d) used a nonparametric alternative as a way of checking the sensitivity of the conclusion to the distribution assumption; and	Y
		e) included a statement about the uncertainty of all estimated or predicted values?	Y
Calculations	26.	Has the investigator: a) calculated percentiles in normal, lognormal or exponential distribution models; and	N
		b) described how percentiles were calculated?	N
Probability maps	27.	Have probability maps been included to show that there is less than a 5% chance of making a false negative error about the quality of material?	N
CONCLUSIONS AND RECOMMENDATIONS *Conclusions*	28.	Has the investigator: a) provided clear and unambiguous conclusions with specific references to the analysis and interpretations that support them;	Y
		b) accompanied each conclusion with a discussion of how it is affected by any underlying assumptions, by the accuracy and precision of the available sample data and by the uncertainty in estimated or predicted values;	Y
		c) classified material based on the data being demonstrably representative of one population; and, for that data set: the upper 90th percentile of the sample concentrations is less than the criterion concentration; and the upper 95 per cent confidence limit of the average concentration of the samples is less than the criterion concentration; and no sample within the data set has a concentration exceeding two times the criterion concentration?	Y

Recommendations	29.	Has the investigator: d) provided clear and unambiguous recommendations; e) informed the client of any other issues of potential concern outside of the goals of the study; and f) provided a rationale with any recommendations, for further investigation?	Y Y Y
REFERENCES *Complete Information*	30.	Has the investigator referenced: a) all data sources, previous studies and other sources (including interviews) that contributed information to the study; and b) any technical literature that provides additional detail on procedures used in the study?	Y Y
APPENDICES *QA/QC*	31.	Has the investigator provided: a) analytical laboratory results, either in printed form or on a diskette (Excel preferred) (mandatory requirement); b) laboratory QA/QC procedures, sampling protocol and the results of check analyses (mandatory requirement); c) drill logs and test pit logs (mandatory requirement); and d) a site map showing sampling locations (mandatory requirement)?	Y Y Y Y
Documentation	32.	Has the investigator included: a) details of statistical computations omitted from the main body of the report; and b) the name and version of the computer software used for the database compilation and the statistical analysis, or a brief description and a reference for any other non-commercial software used in the study?	N N

SITE INVESTIGATION CASE STUDY: GHANA

Transformer Servicing Centre of the Electricity Company of Ghana: Preliminary Site Investigation – Stage 1

Executive Summary

The Electricity Company of Ghana Accra Central Station G (Makola) is one of the sites of environmental concern listed by the Ghana Environmental Protection Agency. This site hosts the company's main transformer servicing workshop and is suspected to be contaminated with polychlorinated biphenyls (PCBs) due to spillage and improper disposal of transformer oil. As a result, a preliminary site investigation (PSI) Stage 1 was undertaken to determine the likelihood of PCB contamination and to ascertain the possible risk to the population in the surrounding areas. The site is located in a very busy district of Accra, the capital of Ghana. Historical information points to the fact that a large number of transformers have been repaired at the centre and there is a high probability of transformer oil spillage. Through conducting a review of historical information, visiting the site, and interviewing relevant parties, this PSI Stage 1 concludes that there is a high probability of PCB contamination on this site. It is therefore recommended that a PSI Stage 2 be conducted to determine the presence or absence of PCB contamination.

1   INTRODUCTION

With the increasing awareness of possible PCB contamination, the need has arisen to investigate areas of the Greater Accra Region in Ghana where extensive transformer maintenance has been conducted. One such area is the Electricity Company of Ghana Accra Central Station G (Makola), where the main transformer service centre is located. A PSI Stage 1 is to be carried out for this site to determine the likelihood of PCB contamination due to historic spillage and improper disposal of transformer oil.

2   SITE LOCATION

The study area (shown in Figure G1.1) is located at No. 10 Independence Road in the central business district of Accra, Ghana. Administratively, this area falls under the Accra Metropolitan Authority. The location lies on Latitude N5°32'51 and Longitude 0°12'21". It is a 1.27 hectare plot of land belonging to the Electricity Company of Ghana.
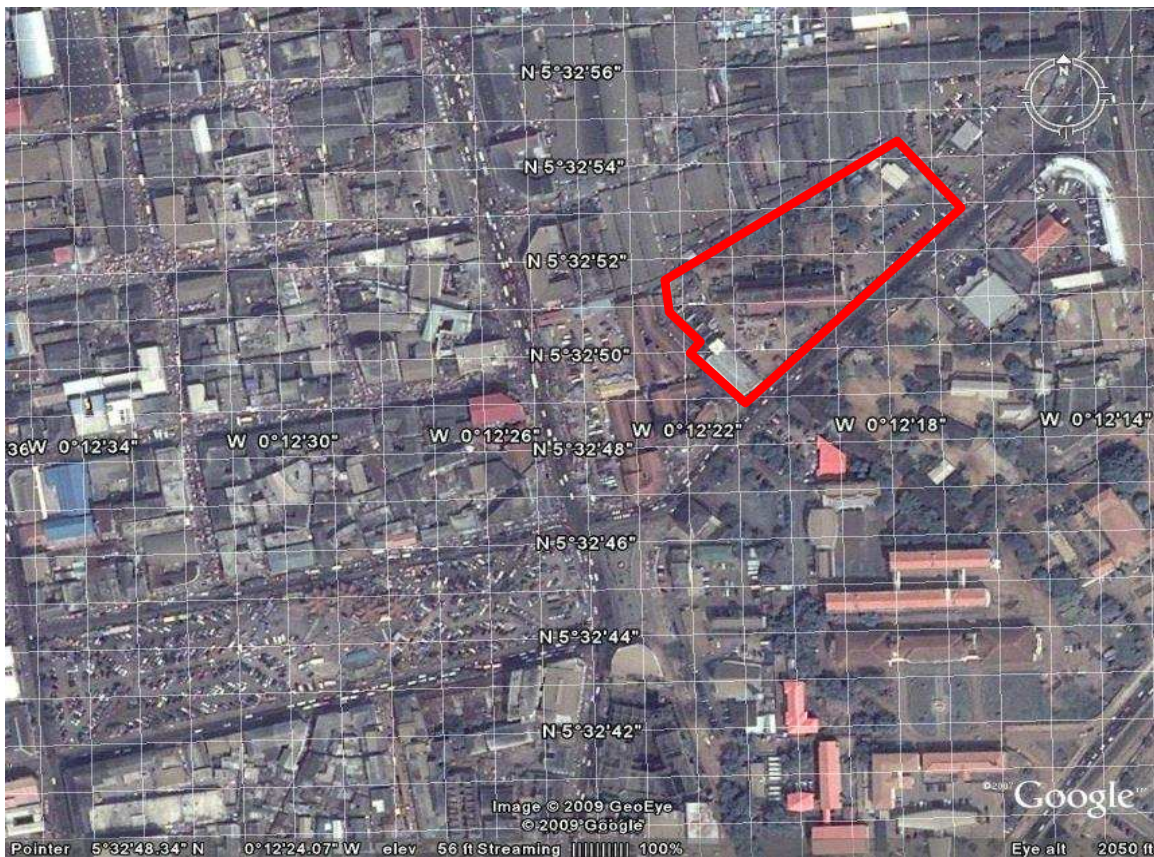
Figure G1.1
Satellite image of the Accra Business Area showing the area under investigation (outlined in red)

Site Record Review

The Property Identification Number, Legal Description and Land Value were not available.

3   SITE PHYSIOGRAPHY

Area Description

The study area is located within the central business district of Accra, the capital of Ghana (shown in Figure G1.2). It is limited in extent by the following facilities: the Makola Market to the north and west, Independence Avenue and the Ghana Law School to the east, and the Makola Shopping Mall to the south. Until the construction of the Akosombo Dam, the study site served as a power generation station for the city of Accra, operating a set of diesel-powered electric generators. Currently, the site functions as a power transmission and control station for the Electricity Company of Ghana (ECG), stepping down high-voltage power from the Akosombo Dam site through transformers, to serve central Accra. The old power house (Generator House) currently serves as the transformer repair workshop.

Figure 1.2
The Electricity Company of Ghana's Accra Sub-Transmission Region, Makola, Accra, Ghana

Site Description

The site is currently used as offices and a servicing facility for ECG. Live high-voltage electrical transformers are also located on the site. A large warehouse, which previously served as a generating station, is used as carpentry and transformer servicing workshops. Metal moulding and welding stations are also located on the site. Several disused transformers are stored out in the open on site, awaiting final disposal. The facility shares a boundary with the Makola Market complex, which is one of the biggest and busiest commercial facilities in Ghana. The market borders the site to the north and east, and is usually heavily populated from Monday to Saturday. Additional major facilities located in the surrounding area are the Ghana Law School to the south, a petroleum filling station to the

northeast, and a public junior high school to the south and across the street from the site. The site is also reported to contain a high density of buried networked high-voltage electricity power cables, which is typical of the central business district of Accra and seriously restricts the extent of subsurface investigation that can be undertaken for this study.

Regional Geology

The geology of the Accra Metropolitan Area has been investigated in detail by mapping outcrops, pitting and drilling, conducted between 1946 and 1963 when the expansion of the city was planned. Kitson (1915), Junner (1940), Bates (1946), Hirst (1948), and Mason (1957) contributed immensely to the understanding of the geology of the Accra area by specialized investigations. The most comprehensive information can, however, be found in the work of Kesse (1985).

The study area is underlain by the Accraian Series. This formation covers much of the Accra Metropolitan Area and extends northwest to Achimota. The Accraian Series is composed of three distinct formations:
- the upper sandstone shale formation, consisting of thin-bedded, fine-grained sandstones with interbeddings of shales
- the middle shale formation, consisting of a fossil-rich argillitic unit that reaches a thickness of over 100 m
- the lower sandstone formation, which is made up of sandstones with a few grits and pebbly beds

Figure G1.3 shows a geological map of the site and its surrounding areas.

Site Geology

With the exception of areas to the north of the project site, namely areas around the Ridge Hospital and the National Museum and Archives, which are underlain by the older Precambrian Dahomeyan (gneisses and schists) and Togo Series (quartzites and schists) Geologic Systems, almost all the administrative and business district of Accra is underlain by the younger Accraian Series of the Devonian age, consisting principally of shales, mudstones, siltstones and sandstones. A detailed geological map of the project area is shown in Figure G1.4. In spite of extensive geological mapping and numerous geotechnical investigations in the area, boundaries between these various rock types remain poorly defined, mainly due to the existence of a deep mantle of residual material over the rocks.

Since the Makola area is the business hub of Accra, it has been subjected to extensive geotechnical investigations over the past two decades. Analyses of the findings of some of these investigations in close proximity to the site, supplemented with detailed studies of deep foundation excavations in the area, indicate the following:
- the actual shale/sandstone contact in the area is slightly to the north of the site, and the site is underlain entirely by shale to a considerable depth
- the shale dips steeply northwards under the sandstone
- unlike other areas underlain by the Accraian rock system, where it was observed that these two rock types are almost invariably in fault contact, there is no conclusive evidence of faulting at the shale/sandstone contact in this area -- the contact is only characterized by a zone of interbedded sandstone and shale

Accraian Series (Devonian age)

	Upper Sandstone-Shale Formation Alternating succession of 10 cm to 1 m thick sandstone and shale.	Foundations of heavy constructions (high-rise buildings, factory sites, bridges) require special considerations because of low shear strength and bearing capacity. Often thick soil cover with ferruginous nodules. Prone to foundation failure during earthquakes if deeply weathered (liquefaction, thixotropy).
	Middle Shale Formation Finely layered, soft rock with horizontal or near-horizontal beds.	
	Lower Sandstone Formation Massive to thick-bedded, well consolidated sandstone; medium grain size.	Good bearing capacity and slope stability. Thin regolith cover which consists of angular rock fragments.

Figure G1.3
Geological map of Central Accra showing the study area (in red) (Source: Ghana Geological Survey Department)
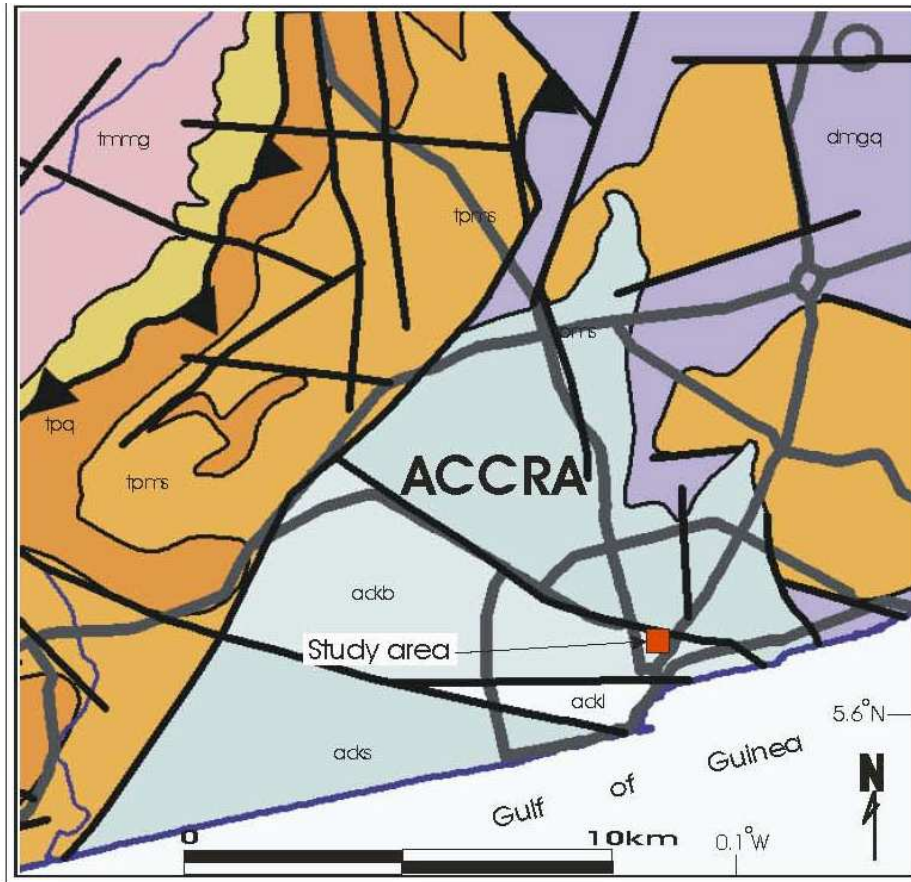
Figure G1.4
Local geology of Accra area

While the residual soils derived from the weathering of the Accraian sandstones are generally competent as foundation material, the shale, on the other hand, weathers to produce a potentially expansive clay whose volumetric activity has been rated as between "medium" and "high", depending on its location. The predominant clay mineral in the residual clay formed from the Accra shale is kaolinite.

Harris (1970) postulated an approximately north-south trending major geologic fault that is inferred to pass just to the west of the site. Previous geotechnical investigations in the area to the southeast of the British Council Centre site have established the existence of this fault. From a geotechnical engineering standpoint, therefore, the two main geologic hazards identified at the site are the potential expansiveness of the weathered Accra shale and the

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possible existence of splinter faults in the vicinity of the site. This latter hazard is significant in view of the established seismicity of the Accra area.

Topography

The study area is generally low-lying, with topographical heights varying between 9.93 m and 12.37 m above mean sea level across the site, with an invert level of 9.4 m recorded in a drain. Generally, the site slopes gently in a southwesterly direction towards a drain.

Vegetation

The site is generally built up in sections with a lateritic fill cover, concrete and bituminous surface dressing. There is therefore very little vegetative cover on site except for some short grasses and shrubs that are located mainly along the western and southern boundaries.

Surface Water, Hydrology and Drainage

The general surface water drainage pattern in the study area is southwesterly towards the southwesterly trending drain that runs from the old power house (transformer repair workshop) to the south, and connects to a major storm drain running through Makola. Of relevance to the study is the possibility of significant southwesterly drainage of any contaminants from the site into the major drain mentioned above, and consequently into the adjoining water bodies and the sea.

The mean annual rainfall varies between 800 mm near the coast to about 1,270 mm close to the foothills of the Akwapim Range. Rainfall is measured on a number of gauges within Accra but the principal rain gauge for the analyses of rainfall is located at the Kotoka International Airport.

Hydrogeology of the Accraian Rock Series

Within the Accraian Series, only the superficial sand and gravel, and the sandstone, horizons can potentially tore and yield groundwater. Depending on the stratigraphic sequence at a given site, the groundwater within the sandstone may be either confined or unconfined. Previous geotechnical investigations elsewhere in Accra have, at times, recorded the groundwater in the sandstones as being under significant artesian pressures. The clay shale horizons will, in general, constitute an aquiclude and cannot be counted upon to yield groundwater. However, a few boreholes are known to be exploiting groundwater within the rocks of the Accraian Series. Estimated yields from these boreholes range between 9 L/min to 210 L/min. These boreholes all terminate in sandstone at depths between 31 m and 60 m. Specific details about the hydrogeology of the site are unavailable.

Surface Conditions, Geomorphology and Drainage

The study area is located in the low-lying part of the Accra Metropolitan Area with an elevation of between 12 m and 30 m. The main city drain runs along the outer wall and the main road. Two other drains occur on the site, and mainly run from the workshop area and drain towards the market area. Flooding is said to occur often during the wet seasons. Runoff in the area has caused siltation in most of the drains although most parts of the site are paved.

See Figures G1.5 and G1.6 for sketches of the site that show the main facilities, surroundings, and drainage.
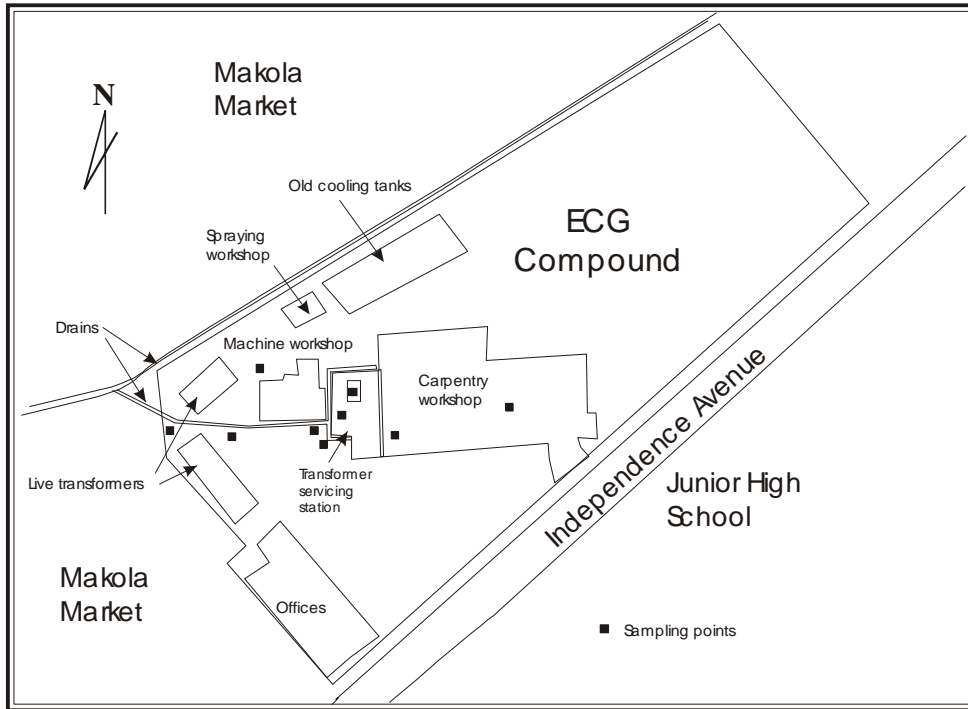
Figure G1.5
A sketch of the site showing the main facilities on the compound and the surrounding area (not to scale).
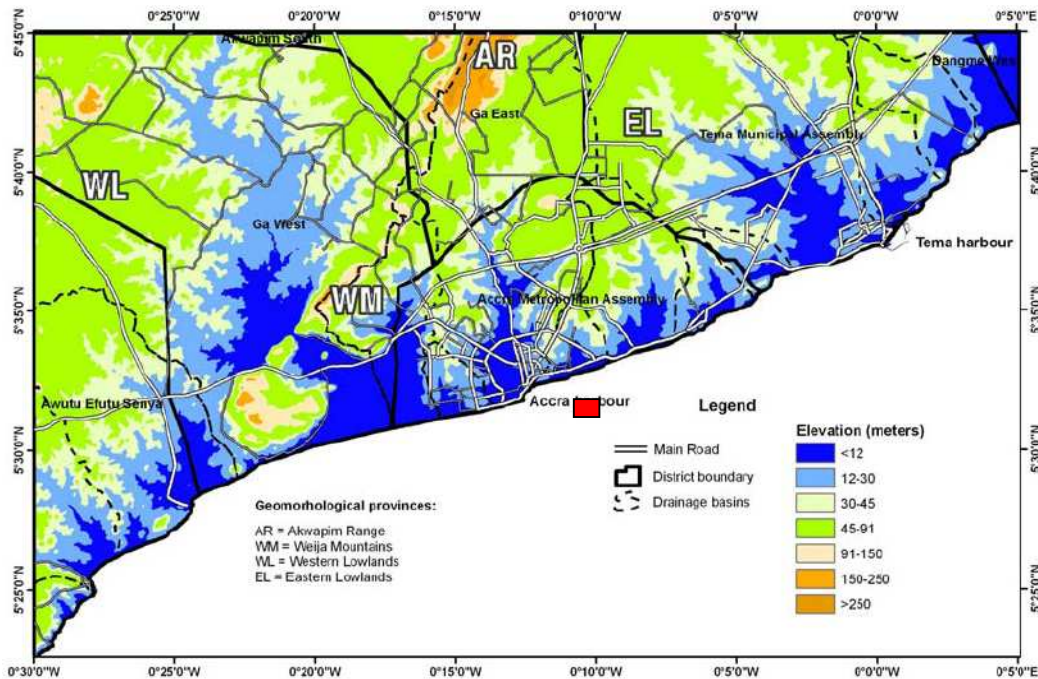
Figure G1.6
Geomorphological map of the Accra Metropolitan Area showing the location of the study area (in red)

Physiography and Climate of Accra

The city of Accra falls within the coastal plains zone of Ghana, with a topography varying from flat near the coast to gently rolling in the vicinity of the foothills of the Akwapim Range to the north and west of the city.

The climate of the Accra area is the coastal savannah type. Mean monthly temperature ranges for 1999-2008 were constant from ~23°C in August to 32°C in March, with an annual average of 26.8°C. Relative humidity is generally high, varying between 65% in the mid-afternoon and 95% at night. The annual evaporation is estimated to be 140 mm. The rainy season is bi-modal, with the major season, accounting for approximately 70% of the total annual rainfall, running from mid-March to mid-July for the same period. The minor rainy season begins in mid-August and ends in October; it varied during 1999-2008, as shown in Figure G1.7.
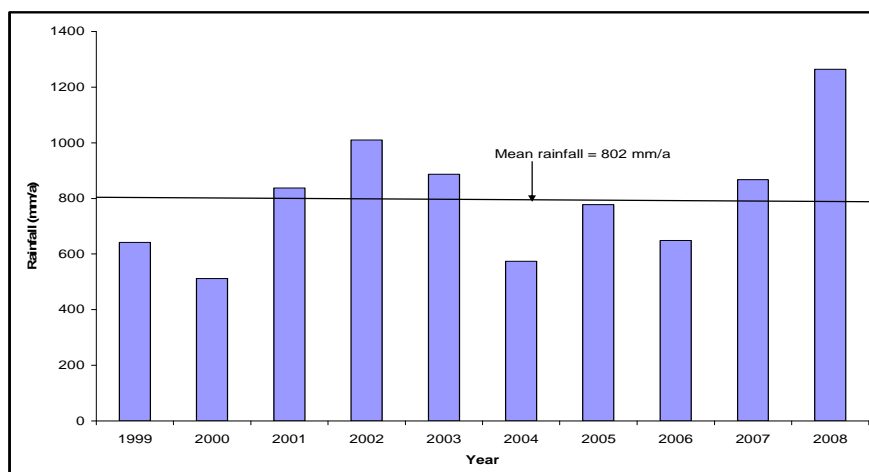
Figure G1.7
Annual rainfall from 1999 to 2008

Wind speeds along the coast of Ghana normally range between 8 km/h and 16.1 km/h. The Accra area recorded its highest wind speed of 107.4 km/h (58 knots) in April 1982. The general wind direction is between south and west-southwest.

4   USAGE AND ACTIVITIES OF SITE AND ADJACENT AREAS

The study site and its adjacent areas are described in Section 3 (Site Description). The study site provides offices and a servicing facility for ECG, the latter including carpentry and transformer servicing workshops in a large warehouse, and metal moulding and welding stations (Figure G1.5). Several unused transformers are temporarily stored in the open space near and around the transformer repair workshop. The facility shares a boundary with the Makola Market complex, which is one of the biggest and busiest commercial facilities in Ghana. Live high-voltage electrical transformers are located on the study site, near the boundary of the marketplace. Additional major facilities located in the surrounding area are the Ghana Law School, a petroleum filling station, and a public junior high school.

The title search for this site is unavailable. Much of the site history and descriptions are unavailable, including the legal plan and information from the Ministry on the presence of contaminated sites within 500 metres of the property. Groundwater, municipal service, and building municipal zoning plans are also not available for the study site.

The site manager and engineers indicated that there is no official record providing details of the period of operation of the warehouse. Due to the former usage, it is likely that the warehouse was tiled at one point in time. At present, the transformers are repaired in this warehouse, and the north-east side of the warehouse is now a carpentry workshop. The date on which these operations were switched is unknown.

5 SITE RECONNAISSANCE AND POTENTIAL CONTAMINATION IDENTIFIED

As a result of the scanty historical data obtained from the information search, a reconnaissance site visit was scheduled, and an official clearance provided, for October 13, 2009. The team of investigators was shown around the facility by ECG's Safety Officer. (See Figures G1.8 to G1.10 for photographs from the visit.) The following observations were made during the visit.

- About 60% of the compound is paved.
- The floor of the area reserved for transformer servicing is tiled except for a small uncovered area visibly soaked with oil (suspected to be transformer oil that has drained from the transformer). Figure G1.8. This area has a mild odour.
- There is a concrete-lined pit in the transformer service area designed to lower the transformer height and improve accessibility. This pit is filled with water that may have leached through cracks in the concrete lining of the pit (See Figure G1.9 (b)). The water is usually pumped out when the pit gets filled up or when use of the pit is required. This indicates of a high water table or the presence of a clay or impermeable layer close to the surface of the site.
- Drainage is mainly through gutters around the old diesel generator building (See Figure G1.8 (a) and (c)). These gutters are filled with rubbish and the drain just outside the transformer servicing area is filled with dark stagnant water (See Figure G1.8 (b) and 9c)). The gutters are silted with a mild odour. The main outlet of the drains runs through the market. (See Figure G1.8 (c)).
- The main room has large windows and, as such, is well ventilated and well lit by natural light.
- Empty tanks, which formerly served as water reservoirs for the diesel generators, are located about 10 m to the north of the main generator building. Some of the tanks are overgrown with weeds (mainly grasses) while others remain empty. See Figure G1.10 (a) and (b).
- Old disused transformers are kept out in the open and also scattered around in the compound. See Figures G1.8 (d) and G1.10 (c).
- Petty trading and the sale of consumable products take place on the compound. The sale of food products to workers seems to be the driving force behind this activity. See Figure G1.9 (c).

Figure G1.8
Photographs were taken on October 13 during site reconnaissance visit: (a) entracne of the transformer serving station (see Figure G1.5), (b) drainage outside the transformer serving station as indicated at the centre of (a), (c) the drainage on the left of (a) near the machine shop towards the market place, (d) outside the transformer serving stationon the right of photo (a), piles of disused transformers.

Figure G1.9
Inside the the transformer serving station: (a) tranformers serving area, washed fluid is kept in a pool, (b) the pool that kept the washed fluid, (c) entrance to the carpentry workshop in the same building (See Figure G1.5), partitioned by a short wall as shown in (a), (d) the carpentry workshop.

Figure G1.10
Around the transformer serving station: (a) empty concrete tanks, formerly served as water reservoirs for diesel generation, (b) close-look in those concrete compartments, (c) transformers scattered around the compound, (d) metal workshop on the north side (left) of the transformer serving station.

Potential Contaminants of Concern

Given the multiple activities, historical uncertainty and complexity of the site within the EGC facility, contaminants of concern could include heavy metals, polycyclic aromatic hydrocarbons (PAHs) and PCBs. However, this report and this Toolkit are focused only on POPs. Since the warehouse is serving as a transformer repair workshop, the most probable contaminants in the area are PCBs originating from transformer oil. Hence this report only deals with PCBs.

Migration Pathways

Since most of the premises are paved, the likely significant migration pathways for the PCBs could be:
- surface runoff to drainage
- air deposition

Indirect pathways could be
- soil and sediment
- groundwater

Potential Receptors of Concern

There is a high risk of inhalation and dermal contact due to PCB-contaminated dust and PCBs migration through open-drainage to the marketplace. Potential receptors of concern in the immediate environment of the station include the ECG staff and people working and shopping in the surrounding market. The most probable contaminants in the area under investigation are PCBs originating from transformer oil that has been spilled during the servicing of transformers. Spillages are generally washed away with water at the end of each day's work, but, due to the poor drainage of the area, the contaminant may have accumulated in unpaved areas of the servicing station. This contamination may have gradually migrated through the unsaturated zone and finally reached the water table. The most probable general migration direction of the pollutant is towards the Makola market, which appears to be at a lower elevation than the study site. Groundwater supply systems in the vicinity of the market could therefore be at risk.

6   CONCLUSION AND RECOMMENDATIONS

Ingestion of PCBs through consumption of contaminated food sold on site, as well as by consumption of contaminated water, seem to be the likely pathways for human exposure to PCBs from this site. Due to the high probability of contamination on this site, it is recommended that a PSI Stage 2 be carried out to determine the presence or absence of PCB contamination.

7   LIMITATIONS OF THE REPORT

During the course of this work, the major limitations were the unavailablility of historical information and data, and lack of government records and other useful information from the

appropriate agencies. During the interviews, the information provided lacked consistency regarding the history of the former warehouse, the ground pavement situation, and historical uses of the site.   The resulting lack of accurate information makes it very difficult to assess the probability of contamination.

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Preliminary Site Investigation (PSI-S1) Checklist for Ghana Case Study October 2009

Section 1	Checklist Preliminary Site Investigation Stage 1 (Items 1–14)	Status Y/N
SUMMARY *Analyses*	1. Does the investigator: a) identify who the major participants are in the investigation; b) state his/her qualifications; c) identify if the study is a first or second stage preliminary site investigation; d) indicate whether the investigation proceeded in stages; e) provide the objectives, methods and procedures that were used in each stage; f) describe the relationship of the two stages; and g) summarize the results, including an evaluation of data that clearly shows the classification, general location and degree of contamination in soil, groundwater, sediments, and surface water?	Y Y Y Y Y Y Y
	2. Does the summary: a) identify what contaminants the analysis program focused on; and b) indicate how reliable the sampling methodology and laboratory analysis was?	Y Y
OBJECTIVES *Goals*	3. Are the goals of the investigation: a) clearly stated; b) in compliance with the scope of work agreed upon with the client; and c) consistent with Ministry of Environment goals and objectives?	Y Y Y
SITE HISTORY & DESCRIPTION *Description of the site*	4. Has the investigator provided: a) a legal description of the property; b) the civic address of the property; c) results from a title search; d) a legal plan from the Land Titles Office; e) information from the ministry on the presence of contaminated sites within 500 metres of the property; f) information from the ministry groundwater section (more relevant for rural properties); g) municipal service plans (if relevant); h) a synopsis of building plans from municipal building inspection departments; i) a municipal zoning plan; j) photos of subject property and adjoining properties; and k) the dates when site visits were conducted?	Y Y N N N N N N N Y Y

Historical review	5. Has the investigator:
	a) reviewed the following information;
	
	  • site plans and diagrams.
	  • aerial photographs.
	  • Site Registry records. (mandatory, index results & detail reports to be included)
	  • city directories
	  • property titles
	  • fire insurance records
	  • information provided by current site owners and those knowledgeable about the site
	  • previous environmental or geotechnical reports relevant to the site.
	b) searched the BC Directory for history of occupiers at subject's civic address;
	c) done additional title searches if necessary to determine site ownership history;
	d) described the historical activities likely to have been present on site;
	e) listed type of contaminants likely to have been associated with each site activity (past/present);
	f) outlined the mechanism of contamination (how,
		
		Y
		Y
		Y
		Y
		N
		N
		Y
		
		N
		N
		N
		Y
		Y
		
		Y

	who, why, source, pathways, receptors); and g) speculated on age of contamination?	Y
Maps	6. Has the investigator: a) *provided a site map, including land use, relevant buildings found on site, dimensions in metres and area of property in hectares;* b) *reviewed aerial photographs of the site and adjacent environs taken prior to and after development, in preparation of historic uses* c) *included natural features such as lakes, rivers, streams found at least partially within the boundaries of the property;* d) *included constructed features such as underground storage tanks, lagoons, ditches, sumps within buildings, and waste storage areas;* e) *provided an area topographic map of 1:20 000 or larger*?	Y Y N Y Y
Surface conditions	7. Has the investigator provided: a) information related to topography (e.g., how it relates to possible groundwater flow and direction of surface runoff); b) an estimation of the percentage of the site presently occupied by buildings and paved areas; c) an estimation of the percentage of the site occupied by buildings and paved areas in past industrial/commercial configurations; d) a general description of adjacent property, water resources; e) the distance to surface water, drinking water supply sensitive environments; f) a discussion of the flood potential of the site?	Y Y Y Y Y Y
Groundwater	8. Has: a) an attempt been made to determine if and where septic systems exist on site, using local government files, etc.; b) an assessment of groundwater vulnerability been provided through information about site soil conditions including texture, structure, thickness, and the content of organic matter and clay minerals; c) a general interpretation of groundwater flow and depth been provided by a qualified hydrogeologist; and d) the assumption behind interpretations of groundwater depth and movement been provided?	Y Y Y Y
Wells	9. If monitoring wells have been installed near the disposal areas previous to this investigation: a) have the monitoring results been reviewed; b) have data been included that indicate why and when a monitoring well was installed and by whom; and c) has any previous geotechnical investigative work been identified and reviewed?	NA
Soil types and soil depths	10. Has the investigator: a) provided soil survey information; b) contacted soil survey personnel, or soil scientists, if no soil survey information is available; c) indicated whether there is visible signs or sources of pollutants on the surface of the soil?	Y Y Y
Climatic conditions Industrial sites Basic preliminary assumptions about contaminants and migration mechanisms Basic preliminary information about liability	11. Has the investigator provided: a) annual precipitation records; b) along with a description of seasonal variations in precipitation; and c) estimates of infiltration rates? 12. For industrial/commercial sites currently operating: a) has the investigator identified manufacturing processes, raw materials, chemicals or fuels used; b) has the investigator identified the potential waste streams; c) has each waste stream's chemical characteristics, volume, and methods of	Y Y N Y Y Y

		treatment and disposal been determined; and	
		d) has the presence of electrical transformers or capacitors been determined?	Y
	13.	Has the investigator:	
		a) provided approximate concentrations and general locations of contaminants (random or non-random, large area extent or confined, near surface or at depth);	Y
		b) discussed reactivity (soluble or non-soluble, volatile or non-volatile)and the toxicity rating (human & ecological) of the potential contaminants of concern;	Y
		c) listed activities in neighbouring properties to a distance of at least 300 metres from the site under investigation;	Y
		d) provided evidence that migration has occurred (reliable or unreliable); and	Y
		e) examined surface waters (including ditches) for signs of contamination?	Y
	14.	Does the investigator:	
		a) provide adequate information about any court or administrative actions, ministry orders, Federal charges under the *Fisheries Act*, etc.?	N

Transformer Servicing Centre of the Electricity Company of Ghana: Preliminary Site Investigation – Stage 2

Executive Summary

The Electricity Company of Ghana Accra Central Station G (Makola) is one of the sites of environmental concern listed by the Ghana Environmental Protection Agency. This site hosts the company's main transformer servicing workshop. The PSI Stage 1 indicated the possibility of contamination by PCBs due to improper disposal and regular spillage of transformer oil on the site. As a result, a PSI Stage 2 was undertaken to determine the presence or absence of PCB contamination on the site.

Surface soil and sediment samples were analyzed for seven PCB congeners using gas chromatography, the seven PCB congeners were compiled to indicate the total PCB content of each sample. The total PCB content of all samples was lower than the AENV Tier 1 screening level (Alberta Environment, 2009; see Table 3.1 of Module 3).

Nevertheless, a detailed site investigation is recommended due to the lack of detailed historic information regarding the facility, the possibility that this site will be converted into a shopping mall in the near future, and the fact that PCB contamination may be present in the subsurface and/or groundwater at the site.

1   INTRODUCTION

The Electricity Company of Ghana Accra Central Station G (Makola) is located in a very busy district of Accra, the capital of Ghana. The results from the PSI Stage 1 indicated the possible presence of PCB contamination at the site due to improper disposal and regular spillage of transformer oil. It is also seemed likely that PCBs migrated through dust, cracks in the pavement surface and open drainage, possibly leading to contamination of the groundwater and the ocean. It is also likely that there have been human health risks due to inhalation or direct contact of contaminants if the site is indeed contaminated with PCBs. As a result, it was recommended that a Stage 2 investigation be conducted.

Scope

The objective of the PSI Stage 2 was to establish the presence or absence of PCB contamination on the site. This investigation included the chemical analysis of surface soil and sediment samples to assess their PCB content.

2   SITE SYNOPSIS

See Section 3 of the PSI Stage 1 report for detailed information about site characteristics, geology, topography, drainage, vegetation, hydrology, and climate. A site conceptual model was developed based on the observations made during the Stage 1 site visit (see Figure G2.1).
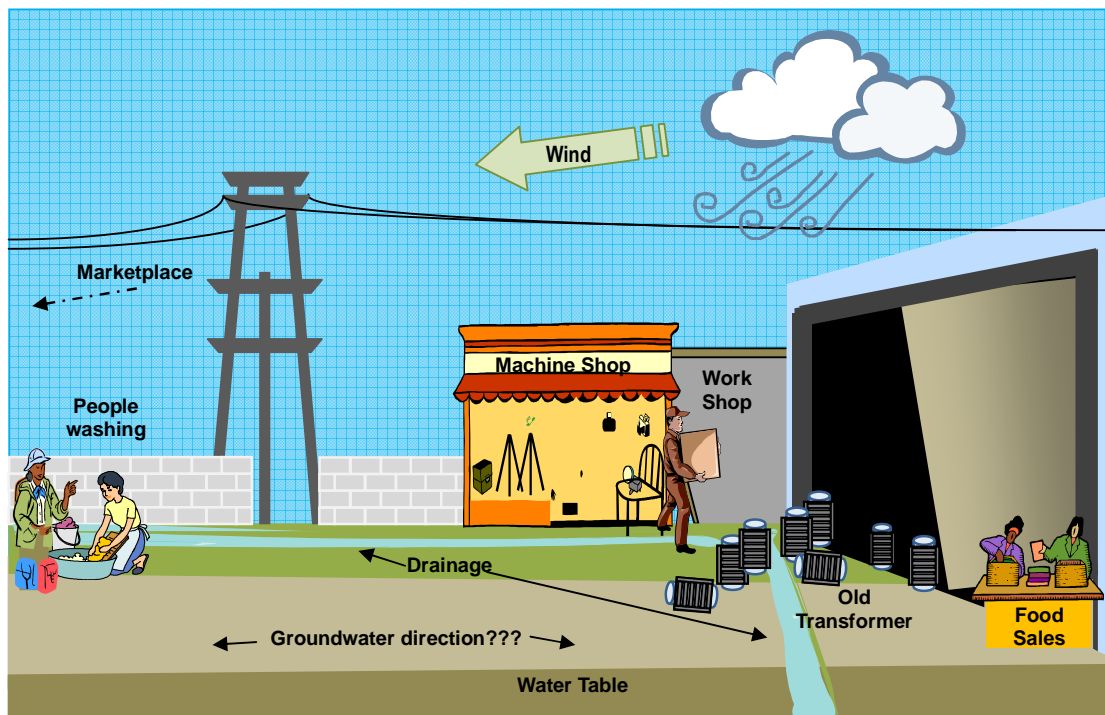
Figure G2.1
Conceptual model of PCBs potential pathways for the Electricity Company of Ghana Accra Central Station G (Makola) site

3   INVESTIGATION PLAN

Rationale

Based on the observations made during the site visit (see Section 5 of the PSI Stage 1 report), the Stage 2 investigation was designed to trace the lateral migration of the suspected contaminants (PCBs) along the path of the main drainage channel towards the market. The main source of contamination is suspected to be the transformer servicing workshop. The contaminant would likely be carried to other areas of the site and out into the market in wastewater resulting from washing of the workshop floor where transformer oil is generally spilled. The wastewater would then be channelled through silted gutters off of the site. There is also the possibility of a gradual vertical migration of the contaminant in unpaved areas, and in places where cracks have developed in the pavement.

Sampling Locations

Surface samples were collected at various locations, as marked in Figure G2.2. Table G2.1 shows the details of the samples taken from the site. A sampling plan for the investigation was designed as follows.
- Site AC1: Unpaved floor of the transformer servicing workshop. Soil in this area was visibly soaked with oil.
- Sites AC2, 3 and 5: At the entrance of the servicing workshop, close to the ramp leading to the workshop. It is suspected that this area is exposed to wastewater from the servicing area when the area is washed.
- Site AC4: Drainage channel close to the workshop. This is suspected to channel the wastewater off of the site into the market. This drainage channel is silted and also contains some rubbish.
- Site AC6: Sediment samples taken from a trench near the market wall.
- Site AC7: Soil in front of old transformer stations. This area is suspected to be contaminated by leaking oils from the old transformers used near this point.
- Sites AC9 and 10: Previously used, together with the transformer servicing workshop, to house municipal diesel electricity generating plants but currently used as a carpentry workshop. Soil samples can serve as a control to the samples from the transformer servicing workshop.
- Note that it was recording error with skipping sample #8.
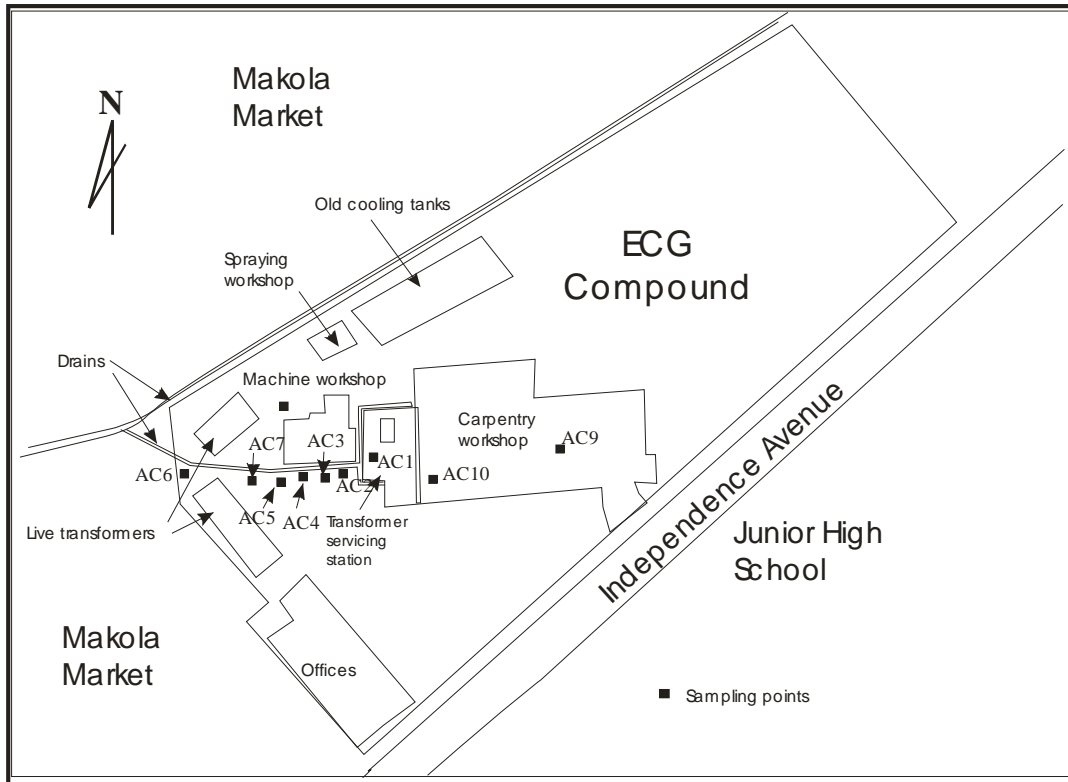
Figure G2.2
Surface samples were collected at various locations within the ECG compound

Table G2.1
Geographical location and type of sample matrix

Sample ID	Longitude (^{0}C)	Latitude (^{0}C)	Matrix
AC 1	5.54753	0.2058	Surface soil
AC 2	5.5475	0.20587	Sediment
AC 3	5.54749	0.20588	Surface soil
AC 4	5.54752	0.20591	Surface soil
AC 5	5.5475	0.20592	Surface soil
AC 6	5.54751	0.20614	Sediment
AC 7	5.54744	0.20602	Surface soil
AC 9	5.54764	0.20547	Surface soil
AC 10	5.54763	0.20565	Surface soil

4 INVESTIGATION METHODOLOGY

Sampling and Preliminary Analysis

Based on observations from the site visit, ten spots were selected for chemical investigation. The main objective of the sampling was to determine the possibility and the extent of PCB contamination in the study area.

Approximately 1 kg samples of surface soil and sediment were collected from each location, using a stainless steel shovel, placed onto pre-treated aluminum foil (cleaned with acetone and baked at 180°C for 12h), wrapped up, and then placed in sealed plastic bags. The samples were stored in an ice chest and transported to the laboratory for analysis.

Sample Extraction

Sample extraction was carried out according to procedures described by Ed-Sverko (2006). A 10 g portion of sieved (200 µm mesh) soil and sediment samples was weighed into a beaker and homogenized with anhydrous sodium sulfate. The mixture was then transferred into an extraction thimble that had been previously washed with *n*-hexane and acetone, and oven-dried. The sample was extracted using 150 mL of *n*-hexane acetone mixture 4:1 (v/v) for six hours using a soxhlet extractor. The extract was evaporated to near dryness with a rotary evaporator at 40°C. Each extract was dissolved in 10 mL *n*-hexane and subjected to cleanup using a C-18 SPE cartridge. The extract was evaporated to dryness and picked up with 2 mL of ethyl acetate for analysis.

Instrumental Analysis

The residues were analyzed using a Varian Gas Chromatograph (GC) CP-3800 equipped with a ^{63}Ni Electron Capture Detector (ECD), which is very sensitive to the detection of halogens. The GC conditions used for the analysis included a capillary column coated with RB-5 (30×0.25 mm, 0.25 µm film thickness), a carrier gas at a flow rate of 1 mL/min, and a make-up gas of Nitrogen at a flow rate of 29 mL/min.

The temperature of the injector (operating in splitless mode) was held at 225^0C, the oven temperature was set at 225^0C, and the ECD was set at 300^0C. The column oven temperature was programmed as follows: 60^0C for two minutes, then increasing by 180^0C/min up to 300^0C, where it was held for 31.8 minutes.

The injection volume of the GC was 1.0 µL. The residues detected by the GC analysis were confirmed by the analysis of the extract on two other columns of different polarities connected to the ECD. The first column was coated with ZB-1 (methyl polysiloxane) and the second column was coated with ZB-17 (58% phenyl, methyl polysiloxane).

5   REGULATORY FRAMEWORK

Due to a lack of appropriate regulatory guidelines in Ghana, Table 3.1 in Module 3 of this Toolkit (the AENV (2009) Tier 1 Screening Levels) was used in this study. The PCB (total) guideline value of 33 mg/kg in the soil of industrial sites was chosen as the appropriate regulatory value.

6   INVESTIGATION RESULTS

Site Physiography and Field Observations

Results from the historical review and site reconnaissance visit are available in Section 3 of the PSI Stage 1 report.

Analytical Results

Table G2.2 shows the PCB content of the surface soil and sediment samples as determined by GC-ECD. Figure G2.3 shows the sampling locations as well as the results for each surface soil and sediment sample.

Table G2.2
Analytical results for PCB content of surface soil and sediment samples

PCB Congeners	AC-1 (mg/kg)	AC-2 (mg/kg)	AC-3 (mg/kg)	AC-4 (mg/kg)	AC-5 (mg/kg)	AC-6 (mg/kg)	AC-7 (mg/kg)	AC-9 (mg/kg)	AC-10 (mg/kg)
PCB 28	0.072	0.117	0.384	0.069	0.573	0.270	0.039	0.090	0.174
PCB 52	0.114	0.111	0.042	0.027	0.129	1.170	0.090	0.036	0.849
PCB 101	0.570	0.747	0	0.114	0.057	0.210	3.489	0.024	0.183
PCB 118	0.498	1.152	1.479	0.093	0.048	0.432	5.988	0.033	0.234
PCB 153	2.511	5.799	4.605	0.297	1.743	1.548	1.161	0.105	0.237
PCB 138	2.532	6.738	0.756	0.246	1.668	1.047	0	0	0.621
PCB 180	3.123	6.057	5.067	1.338	2.406	2.043	0	0.069	0.417
TOTAL	9.42	20.721	12.333	2.184	6.624	6.72	10.767	0.357	2.715
Standard	33	33	33	33	33	33	33	33	33
Status	clean	clean	clean	clean	clean	clean	clean	clean	clean

Transformer repair Building

AC9

AC10

Transformer

Workshop

BH2 AC4
AC6 BH2A AC2 AC1
BH3 AC3 BH1A
AC5

Old Transformer

AC7

Name of PCB Congeners	A-10 (mg/kg)	Name of PCB Congeners	A-9 (mg/kg)
PCB 28	0.174	PCB 28	0.09
PCB 52	0.849	PCB 52	0.036
PCB 101	0.183	PCB 101	0.024
PCB 118	0.234	PCB 118	0.033
PCB 153	0.237	PCB 153	0.105
PCB 138	0.621	PCB 138	0
PCB 180	0.417	PCB 180	0.069
TOTAL	2.715	TOTAL	0.357

Name of PCB Congeners	A-6 (mg/kg)
PCB 28	0.27
PCB 52	1.17
PCB 101	0.21
PCB 118	0.432
PCB 153	1.548
PCB 138	1.047
PCB 180	2.043
TOTAL	6.72

Name of PCB Congeners	A-7 (mg/kg)
PCB 28	0.039
PCB 52	0.09
PCB 101	3.489
PCB 118	5.988
PCB 153	1.161
PCB 138	0
PCB 180	0
TOTAL	10.767

Name of PCB Congeners	A-5 (mg/kg)
PCB 28	0.573
PCB 52	0.129
PCB 101	0.057
PCB 118	0.048
PCB 153	1.743
PCB 138	1.668
PCB 180	2.406
TOTAL	6.624

Name of PCB Congeners	A-4 (mg/kg)
PCB 28	0.069
PCB 52	0.027
PCB 101	0.114
PCB 118	0.093
PCB 153	0.297
PCB 138	0.246
PCB 180	1.338
TOTAL	2.184

Name of PCB Congeners	A-3 (mg/kg)
PCB 28	0.384
PCB 52	0.042
PCB 101	0
PCB 118	1.479
PCB 153	4.605
PCB 138	0.756
PCB 180	5.067
TOTAL	12.333

Name of PCB Congeners	A-2 (mg/kg)
PCB 28	0.117
PCB 52	0.111
PCB 101	0.747
PCB 118	1.152
PCB 153	5.799
PCB 138	6.738
PCB 180	6.057
TOTAL	20.721

Name of PCB Congeners	A-1 (mg/kg)
PCB 28	0.072
PCB 52	0.114
PCB 101	0.57
PCB 118	0.498
PCB 153	2.511
PCB 138	2.532
PCB 180	3.123
TOTAL	9.42

PROJECT
UNIDO Contamination Study

TITLE
PCB CONTAMINATION STUDIES

LOCATION
ECG STATION G (Makola)

CLIENT
UNIDO

Scale
1:400   Drwg No.

Date
January, 2010

☒ Surface sample

● Proposed site for borehole drilling

Figure G2.3
Map showing sampling locations and PCB content of surface soil and sediment samples

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The total PCB concentrations detected in this study ranged from 0.367 mg/kg to 20.72 mg/kg. These values are both below the level given in Table 3.1 of Module 3 (AENV 2009, Tier 1 Screening Level of PCBs in commercial or industrial areas), which is 33 mg/kg. AC2 and AC3 located on the down slope of the transformer repair workshop, had the highest PCB concentrations, likely due to the surface runoff for the repair shop. AC 9 and AC10, which are both located at the other end of the repair building in an area partitioned by a wall, had the lowest PCB concentrations.

The relatively low levels detected in this study can be potentially ascribed to the following reasons:

- Only seven indicator PCBs were used in the standard for this analysis; however, the PCB mixtures used as dielectrics in transformers and capacitors usually contain not less than 20 congeners in a mixture. Therefore, only seven of the 20 or more PCBs were included in the total PCB contents calculated in this study.
- The soil in the top 10 cm layer from which samples were taken in this was sandy. The porous nature of the soil could have enhanced percolation of the contaminants to the subsurface.
- The low levels of contaminants could be due to the fact that during washing and clean-up of these transformers and the workshop, the water could have aided seepage of the contaminants into the soil due to the texture of the topsoil.
- The particle size of the soils determines the adsorption capacities of most persistent organic pollutants, especially PCBs (Elder and Weber, 1980). The large particle sizes of the top 10 cm layer of the sample locations does not aid in the adsorption of PCBs.
- During rainfall or windy periods, the topsoil could be eroded, and this could contribute to the low levels of contaminants detected.
- Though access to the site is supposed to be restricted, in reality it is not so, as hawkers, traders and other people frequently use the site for their activities. This could also have contributed to the low levels of contaminants detected due to frequent disturbances of the topsoil.

Work done on some selected transformers using both CLOR-N-OIL test kits and Neutron Activation Analysis has established that about 21% of transformers could be contaminated with PCBs (Buah-Kwofie, 2008).

7   CONCLUSION AND RECOMMENDATIONS

Although the PSI Stage 2 indicated a likelihood of PCB contamination on this site due to improper disposal and spillage of transformer oil, the Stage 2 analytical results did not indicate high PCB levels, in the surface soils or sediments, that are above the permissible value given in Table 3.1 of Module 3 (AENV 2009, Tier 1 Screening Levels of PCBs in commercial or industrial areas.).

According to the EPA of Ghana, the ECG site might be redeveloped into a modern shopping mall. Given the uncertainties of the PSI-S2 and the finding of significant (though below limiting) PCB concentrations are found to some extent in all surface samples, in the down-

slope of the transformer repair workshop and the drainage, care must be taken to protect human health.

8 LIMITATIONS OF THE REPORT

Due to the lack of historical information, the finding that records regarding the facility are poorly kept, and inadequate and inconsistent responses from the personnel interviewed, there was very little reliable information which could be used to develop a sampling strategy for PSI-S2. Moreover, most of the areas are paved. Hence the samples collected likely reflected dust deposition rather than top soil samples.

The surface sampling was carried out on October 13, 2009. It should be noted that the observations and the laboratory analytical results only apply to the actual date of sampling.

Due to budget restrictions and limited analytical capacity, only seven congeners of the 20 or more usually identified were determined in this study. Because of the temporal and spatial variations in the usage of the site, the extent of contamination is likely to vary with time and location. With these limitations, the authors assume no responsibility and liability for these results being used in the future.

It should also be noted that this investigation focused solely on PCB contamination. In view of the multiple activities and the complexity of the site, it is highly likely that other contaminants, such as heavy metals and PAHs, are also present at the site.

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Buah-Kwofie A. 2008. Polychlorinated Byphenyls (PCBs) Levels in Transformers from Selected Sensitive Areas in the Greater Accra Region. Thesis. pp 123.

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Elder G. and Weber K. 1980. Chlorinated phenols in sediments and suspended matter of the Weber estuary. *Chemosphere* **9**: 111-118.

Preliminary Site Investigation Checklist for Ghana Case Study October 2009

SECTION 2	Preliminary site investigation Stage 2 may include 15–24	Status Y/N
DATA *Goals of the study*	15. Has the investigator discussed the following about the potential contaminants of concern: a) what are the goals of the preliminary site investigation; and b) will analysis of the populations identified in the study lead to achieving these goals?	 Y Y
Populations	16. Does the sampling plan and data: a) adequately identify the contaminants that exist and represent their general distribution; b) establish the physical and chemical controls on contaminant distribution?	 Y Y
Plans	17. Has the investigator: a) explained the rationale behind the sampling plan; b) provided a sampling plan that reflects the potential sources, pathways, and receptors of contaminants; c) over-sampled to compensate invalidated results (broken bags, lost labels, etc.); d) avoided collecting composite samples; e) provided a rationale for using composites or a combination of composite and discrete samples, f) detailed the procedures used to collect, record; confirm and verify the database; g) provided an adequate location for each sample (e.g., has the sample grid been tied into UTM co-ordinates); h) has the investigator attempted to determine the background soil conditions for the parameters being investigated; and i) does the investigator provide a rationale for choosing the area used to represent ambient conditions?	 Y Y Y Y Y Y Y Y Y
	18. If previous studies have been used: a) have the data been summarized and presented in the report; b) have the data been used to add to the density of sampling locations; c) has the source of additional data been identified and its use justified; and d) has the investigator given reasons for including or excluding data from previous studies?	 Y Y Y Y
Protocols	19. Have field sampling procedures been carried out according to: a) ministry protocols where available; and b) if modified, presented justification for such modifications?	 Y Y
	20. Has the investigator: a) included the original quality assurance plan; b) run a complete check of all data against original records; c) provided documentation of the reliability of any data that is significant to the study's conclusions; d) shown that the analytical methods used for all samples conform with methods accepted by ministry recommendations; e) used paired analyses of duplicate samples (where samples are collected separately in the same immediate area); f) used paired analyses of split samples of the same material especially where suspected contaminant levels are believed to be at their highest concentrations; g) discussed the possible reasons for differences between splits and field sample duplicates; h) have recommended ministry lab services QA/QC protocols been followed; and	 Y Y Y Y Y Y Y Y

		i) documented any corrective action taken if QA/QC reveals significant bias or high imprecision?	Y
EXPLORATORY DATA ANALYSES	21.	For univariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; c) made use of graphical representations of the data, such as histograms, or probability plots; d) used summary statistics that describe the centre, location, spread, and shape of the univariate distribution; and e) used logarithmic scaling, if the data are skewed, to make graphical presentations more informative?	N N N N N
	22.	For bivariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; and c) used scatter plots that display the relationship between pairs of variables and linear and rank correlation coefficients that summarize the strength of the relationship?	N N N
Outliers	23.	For all distributions, has the investigator: a) used rank correlation as an alternative to linear correlation to reduce sensitivity to outliers when summarizing the relationship of two variables; b) used probability plots, scatter plots and data postings to identify outliers; c) determined whether any outliers require that any critical assumptions need to be modified; d) determined the reasons for the existence of the outlier; e) documented the reasons for and provided all relevant information about any outlier value that has been discarded; and f) taken a new sample at a random location within one metre of a discarded outlier sample?	N N N N N N
STATISTICAL ANALYSIS AND INTERPRETATION *Assumptions*	24.	Has the investigator: a) described the statistical tools and procedures used to analyze and interpret the data along with their underlying assumptions; b) included calculations and assumptions for population standard deviations estimated for the purposes of a confidence interval calculation; c) provided a rationale for the method used to deal with non-detectable data; d) used a nonparametric alternative as a way of checking the sensitivity of the conclusion to the distribution assumption; and e) included a statement about the uncertainty of all estimated or predicted values?	N N N N N
CONCLUSIONS AND RECOMMENDATIONS *Conclusions*	25.	Has the investigator: a) identified high risk concerns; b) provided clear and unambiguous conclusions with specific references to the analysis and interpretations that support them; and c) discussed how each conclusion is affected by any underlying assumptions, by the accuracy and precision of the available sample data and by the uncertainty in estimated or predicted values?	Y Y Y
Recommendations	26.	Has the investigator: a) provided clear and unambiguous recommendations; b) informed the client of any other issues of potential concern outside of the original goals of the study; and c) provided rationale with any recommendations for further investigation?	Y Y Y

REFERENCES *Complete Information*	27.	Has the investigator referenced: a) all data sources, previous studies and other sources (including interviews) that contributed information to the study; and b) any technical literature that provides additional detail on procedures used in the study?	Y Y
APPENDICES *QA/QC* *Documentation*	28.	Has the investigator provided: a) analytical laboratory results, either in printed form or on a diskette (Excel preferred) (mandatory requirement); b) Laboratory QA/QC procedures, sampling protocol and the results of check analyses (mandatory requirement); c) drill logs and test pit logs (mandatory requirement); and d) a site map showing sampling locations? (mandatory requirement – may be included in the main report)	N N N N
	29.	Has the investigator included: a) details of statistical computations omitted from the main body of the report; and b) if used, the name and version of the computer software utilized for the data base compilation and the statistical analysis, or a brief description and a reference for any other non-commercial software used in the study?	N N

Transformer Servicing Centre of the Electricity Company of Ghana: Detailed Site Investigation

Executive Summary

A preliminary site investigation (Stages 1 and 2) was carried out on the compound of the Electricity Company of Ghana (Station G), Makola, in the Accra business district, a heavily populated area in the national capital. The studies revealed the presence of PCBs in the area. As a result, a detailed site investigation was executed to determine the actual extent of contamination and the risk it poses to the general public who patronize the ECG compound and the Makola Market.

Based on PSI results, three sites were selected for drilling. This was seen an opportunity to study and record the detailed geology of the area. Drill core were examined and samples taken at regular intervals from each well for the determination of PCB concentrations. Other field tests, such as the Standard Penetration Test (SPT), were also performed because there was lack of site geological information.

A summary of the results from analysis clearly showed PCB contamination in the study area. High levels of contamination were restricted to the upper level of the drilled boreholes composed of the lateritic soil. The shale region, however, together with the thick unsaturated moderately dense compacted lateritic fill zone, serves as a natural barrier that protects the aquifer from this contamination. Possible migration of the contaminant was inferred to be in the direction of the Makola Market where there is a sharp thickening of the engineered moderately dense lateritic clayey sandy gravel.

It is recommended that a comprehensive surficial sampling (i.e. PSI Stage 2) need to be performed. Based on the additional surface sample results, the investigator then decides if further action is needed

1   INTRODUCTION

Although Ghana has never manufactured PCBs, they have been used extensively in transformers and capacitors as dielectric fluids for both electricity generation and distribution. While the health and environmental implications associated with exposure to PCBs are known worldwide, it has only become an issue of concern in Ghana recently. The results of the PSI, Stage 1 and Stage 2, revealed the presence of PCBs at the site. A detailed site investigation will ascertain the extent of the contamination and the possible migration pathways through the subsurface.

2   SITE SYNOPSIS

Site details are available in the accompanying PSI Stage 1 and Stage 2 reports. Based on the PSIs, an improved site conceptual model was developed with the focus on exposure and receptors as shown in Figure G3.1.
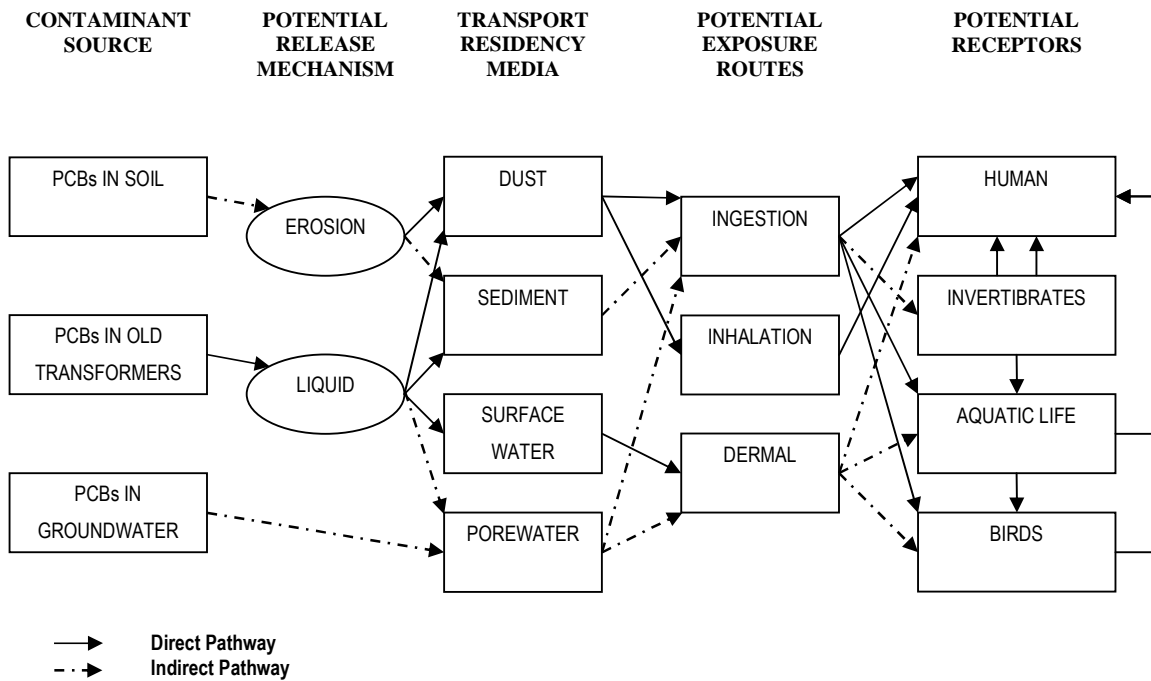
Figure G3.1
Exposure Model for Potential Receptors at Electricity Company of Ghana (ECG)

3   INVESTIGATION PLAN

Figures G3.2 and G3.3 show the results of the topographic survey conducted in Stage 2, with the sites selected for borehole drilling highlighted. All aspects of the fieldwork carried out as part of this study are related to this working grid. The boreholes were selected based on the

likely migration of the contaminant and patterns of contamination at the site, taking into consideration the site's topography with reference to the source of PCB contamination.

Based on the results of the PSI Stage 2, three locations were selected for borehole drilling to monitor the extent of PCB contamination. Two of the boreholes were located near the transformer workshop, with the other borehole close to the main drainage outlet (see Figures G3.1 and G3.2). From the first borehole (BH1), which is located about one metre from the main transformer workshop, seven grab samples of soil were taken to a depth of five metres and labelled BH1, 1-7. The second borehole (BH2) was drilled directly in front of a store room, situated close to the main transformer workshop. Seven grab samples of soil were taken from this borehole to a depth of 5.5 m and labelled BH2, 1-7. A third borehole (BH3) was drilled at a location close to the Makola Market, and a drain leading to the market, in order to assess the possible transport of PCB contamination into the market. It is also close to a drain leading to the market. Ten grab samples of soil (BH3, 1-10) were taken from BH3, which was 6 m deep. Groundwater samples were also taken from BH1 and BH2.
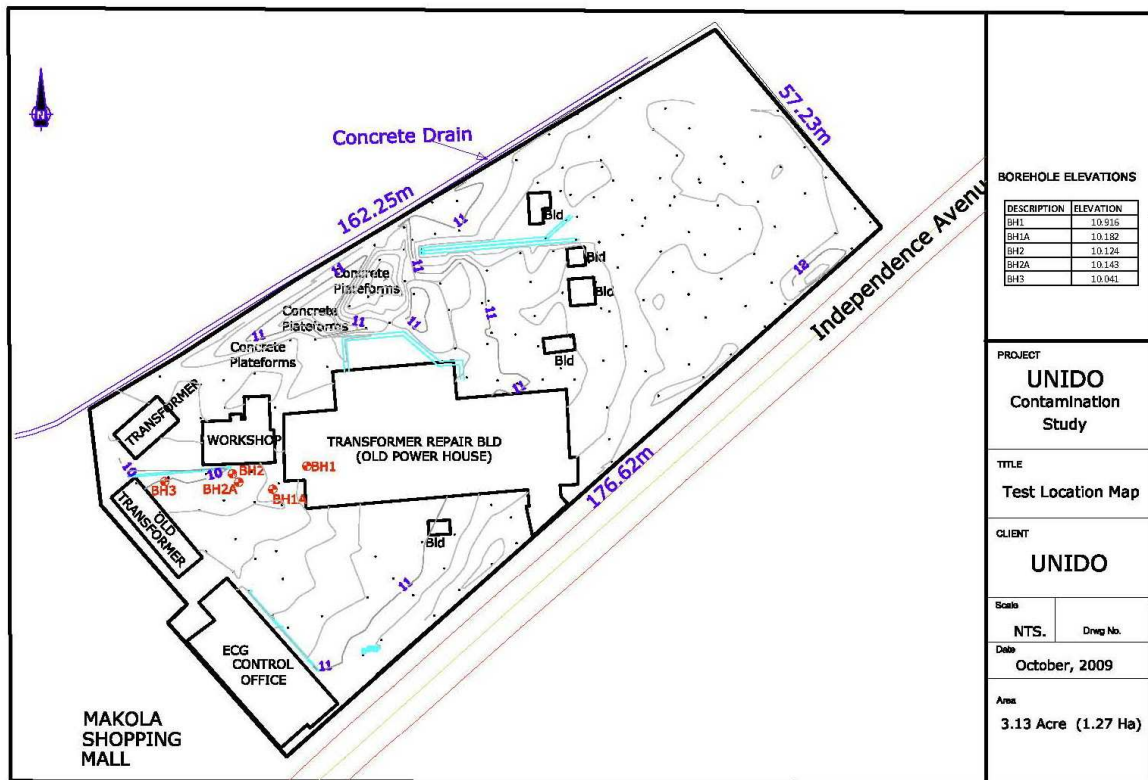
Figure G3.1
Map of the ECG Station G showing locations selected for drilling

Figure G3.2
Digital terrain model of ECG station G showing locations selected for drilling

4   INVESTIGATION METHODOLOGY

Geotechnical Investigations

The borehole drilling operations and the associated soil sampling and field testing were carried out in accordance with recommended practice as set out in the relevant British Standards (BS 5930 – 1999).

In order to meet the DSI's objectives, ensure compliance with soil sample recovery requirements, avoid/limit cross-contamination, and perform the specified field tests, it was deemed necessary to deploy a drilling rig capable of penetrating soft ground and rotary drilling through rock.

The field tests that that are required for this particular DSI include the Standard Penetration Test (SPT) and the in–situ permeability test. However, it was not possible to perform the in-situ permeability test due to time limitations. The results of the detailed SPTs were analyzed in accordance with the stipulations of the relevant British Standards (BS 5930-1999). The SPTs were conducted between the levels of recovery of undisturbed soil samples whenever possible and an automatic trip hammer was used to ensure uniformity of energy input. The blow-counts were recorded as a function of depth on the logs of the relevant boreholes.

An American-made all-purpose Diedrich D-25 geotechnical rotary drilling rig was used for soil and rock exploration. This rig is also capable of installing monitoring wells for the purpose

of geotechnical and environmental investigations. The rig is fitted with standard drilling strings to recover various diameters of disturbed and undisturbed soil samples and rock cores. It includes a hydraulically operated piston sampler and core barrel, a hollow and solid stem continuous fleet auger, and a mechanically operated SPT hammer with split spoon assembly.

The depths attained in the boreholes in soft ground are shown in Table G3.1. All borehole drillings were terminated upon attainment of refusal conditions in SPT blow count N-values, which occurred upon encountering the weathered shale rock head. The final depths of the boreholes in soft ground ranged from 5.0 m in BH1, 5.5 m in BH2, to 6.0 m in BH3.

Table G3.1
Borehole Locations and Depths

Borehole No.	Coordinates		Ground Elevation (m)	Depth Attained in Rotary Drilling (m)
	Eastings	Northings		
BH1	97129.964	362262.158	10.182	5.0
BH2	97131.508	362254.618	10.143	5.5
BH3	97131.677	362238.227	10.041	6.0

Sampling Protocol

Geotechnical and analytical sampling of soil and water

Wherever possible, undisturbed soil samples were recovered from appropriate depths in all the boreholes in accordance with recommended practice. In general, undisturbed soil samples were recovered in standard Shelby-Tubes and sometimes with core barrels, which were later extruded using a specialized hydraulic-operated system attached to the drilling rig (Plate 2). The outer parts of the samples were scraped off and the central portion collected into pre-treated aluminum foil. Samples were taken at specified depth ranges and, where a significant change in soil profile occurred, more than one sample was taken.

Individual soil samples were labelled and placed in zip-lock plastic bags. Groundwater samples were collected in labelled 2.5 L amber glass bottles. Both soil and groundwater samples were stored on ice in an ice chest and transported to the laboratory for analysis. In the laboratory, samples were stored at -20^0C until analysis. Water samples were pre-filtered through 0.45 µm glass fibre filters (Whatman) to remove suspended material. The borehole soil samples were air-dried and sieved through a 200 µm stainless steel sieve using a mechanical shaker.

Extraction of soil and water samples

Extraction of soil samples was carried out according to procedures described by Muir and Sverko (2006). A 10 g portion of sieved soil samples was weighed into a beaker and homogenized with anhydrous sodium sulfate. The mixture was then transferred into an extraction thimble that had been previously washed with *n*-hexane and acetone and oven-dried. The sample was extracted using 150 mL of *n*-hexane acetone mixture 4:1 v/v for six hours using a soxhlet extractor. The extract was evaporated to near dryness using a rotary evaporator at 40°C. Each extract was dissolved in 10 mL of *n*-hexane and subjected to

cleanup using Florisil. The extract was evaporated to dryness and picked up in 1 mL of ethyl acetate for analysis.

Water samples were extracted according to the procedure described by Pandit *et al.* (2006). A 50 mL volume of *n*-hexane was introduced into a 2 L separating funnel containing 1 L of filtered water and shaken vigorously for five minutes, and then allowed to settle. After complete separation, the organic phase was drained into a 250 mL conical flask while the aqueous phase was re-extracted twice with 50 mL of n-hexane. The extracted organic phase was combined and dried by passing through a glass funnel containing anhydrous sodium sulfate. The hexane fraction was concentrated using a rotary evaporator and then cleaned up according to the cleanup procedure described above.

Instrumental Analysis

The residues were analyzed using a Varian CP-3800 Gas Chromatograph equipped with a ^{63}Ni Electron Capture Detector, which is very sensitive to the detection of halogens. The GC conditions used for the analysis included a capillary column coated with RB-5 (30×0.25 mm, 0.25 µm film thickness), a carrier gas at a flow rate of 1 mL/min and a make-up gas of nitrogen at a flow rate of 29 mL/min.

The temperature of the injector (operating in splitless mode) was held at 225°C, the oven temperature was set at 225°C and the ECD temperature was set at 300°C. The column oven temperature was programmed as follows: 60°C for two minutes, 180°C/min up to 300°C, held for 31.8 minutes.

The injection volume of the GC was 1.0 µL. The residues detected by GC analysis were confirmed by the analysis of the extract on two other columns of different polarities. The first column was coated with ZB-1 (methyl polysiloxane) connected to the ECD, and the second column was coated with ZB-17 (58% phenyl, methyl polysiloxane) connected to the ECD. Some indicator PCB congeners recommended by USEPA were analyzed (IUPAC NOs: 28, 52, 101, 118, 138 and 153). The quantitative evaluation of the results was performed based on a comparison of the peak areas corresponding to the indicator congeners in the chromatograms of the sample in the standard.

Quality Assurance and Quality Control

The quality of the sampling process was assured by changing the core barrel attached to the drilling rig after each borehole. The stainless steel scoops used to collect the samples were washed and dried after each sampling process to avoid cross-contamination. All glassware was scrubbed with a brush in hot water and detergent, then rinsed with acetone and hexane. The glassware was dried in an oven at 180°C before use. The analysis of solvent blanks preceded the analysis of the actual sample. Each batch of samples was analyzed in duplicate. All reagents used during the analysis were exposed to the same extraction procedures and, subsequently, run to check for interfering substances. In the blank for each extraction procedure, no peak was detected.

3 REGULATORY FRAMEWORK

Ghana adopted *Agenda 21* at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in 1992. This Agenda seeks, among other things, to enhance the sound management of chemicals. Of particular interest to Ghana is Chapter 19, which deals with the environmentally sound management of chemicals, including illegal international traffic in toxic and dangerous products. Ghana is therefore expected to develop actions and priorities relating to the following:

- information exchange on toxic chemicals and chemicals risks
- harmonization of classification and labelling of chemicals
- expanding and accelerating international assessment of chemical risks
- establishment of risk reduction programmes
- prevention of illegal international traffic in toxic and dangerous products
- strengthening national capabilities and capacities for the management of chemicals

Within this context, and in line with the Ghana Environmental Action Plan, the Government of Ghana's policy on the environment seeks among other things to "take appropriate measures, irrespective of the existing levels of environmental pollution and extent of degradation, to control pollution and the importation and use of potentially toxic chemicals." (National Implementation Plan of the Stockholm Convention on POPs)[1]

POPs fall under the category of potentially toxic chemicals, and Ghana, as an early adopter and ratifier of the Convention, is committed to the effective implementation of the provisions and obligations of the Stockholm Convention on POPs.

As a first step to ensure sound management of chemicals in Ghana, a national profile for chemicals management was prepared in 1997. This document provides a comprehensive assessment of the national chemicals management infrastructure relating to the legal, institutional, administrative and technical aspects, along with an understanding of the nature and extent of chemicals availability and use. The profile has been updated to take on the particular issues associated with POPs. A national action program for an integrated chemicals management program in Ghana was also initiated in 1997.

The overall objective of the sound management of POPs in Ghana is to strengthen the national capacity and capability to deliver a comprehensive assessment of the threats posed by exposure of humans and the environment to POPs. Appropriate actions, activities and strategies will then be implemented to reduce and ultimately eliminate POPs from the environment. as envisaged under the Stockholm Convention. The Ghana National Implementation Plan (NIP) will build on existing work and assessments, and form an integral part of the national integrated chemicals management program. It will take due account of the aims of the national sustainable development in the sense of social, economic and environmental policies and actions in order to maximize their overall benefits. This will avoid "reinventing the wheel" and link the NIP to related national chemicals management initiatives where possible to ensure maximum efficiency and reduce duplication of effort. See PSI Stage 2 for details about the regulatory framework. In view of the above, we have

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[1] http://www.pops.int

adopted the Tier 1 Screening Level of Tables 3.1 and 3.2 of Module 3 (AENV, 1009a) to identify if the site is contaminated with PCBs and if there is risk.

5 INVESTIGATION RESULTS

Geology of Project Area

A detailed description of the geology of the area can be found in Section 3 of the PSI Stage 1 report, along with a geological map with the study area highlighted (see Figure G1.3 of the PSI Stage 1 report).

Characteristics of the Surficial Soils and Nature of the Bedrock

The subsurface exploration program, carried out as part of these studies, revealed stratigraphic characteristics typical of areas underlain by the Accraian Series of rocks. Generally, the boreholes revealed a fairly uniform stratigraphy consisting of the following succession:

- an average 0.5 m thickness of compact, moderately dense to dense, reddish-brown lateritic clayey-silty–sand-gravel
- this is underlain generally by moderately stiff, mottled greyish reddish-brown gravelly sandy clay to a maximum depth of 3.0 m in BH1
- the stratigraphy then grades into a highly weathered and decomposed shale, and generally terminates in the weathered shale at a maximum depth of 6.0 m in BH3

The geotechnical engineering laboratory test results showed that the plasticity index is approximately 19 for the lateritic gravel and around 29 for the random fill. However, the random fill encountered in BH3 gave a plasticity index value of 10. The plasticity index of the decomposed clay gave an average value of 36..

The project area has been mapped as underlain by the Accraian Series of rocks. The information acquired from the boreholes sunk in this DSI agreed with the conclusion drawn from previous investigations that the project area is, in fact, underlain by shales of the Accraian Series. The shales are known to decompose to give very stiff clays that are generally impermeable. The existence of shale and its decomposition products may be of particular relevance to the study because of their potential to act as a liner to prevent, or at least slow down, the rate of infiltration of PCB contaminants into the groundwater. Figure G3.4 illustrates the soil profile of the study site.
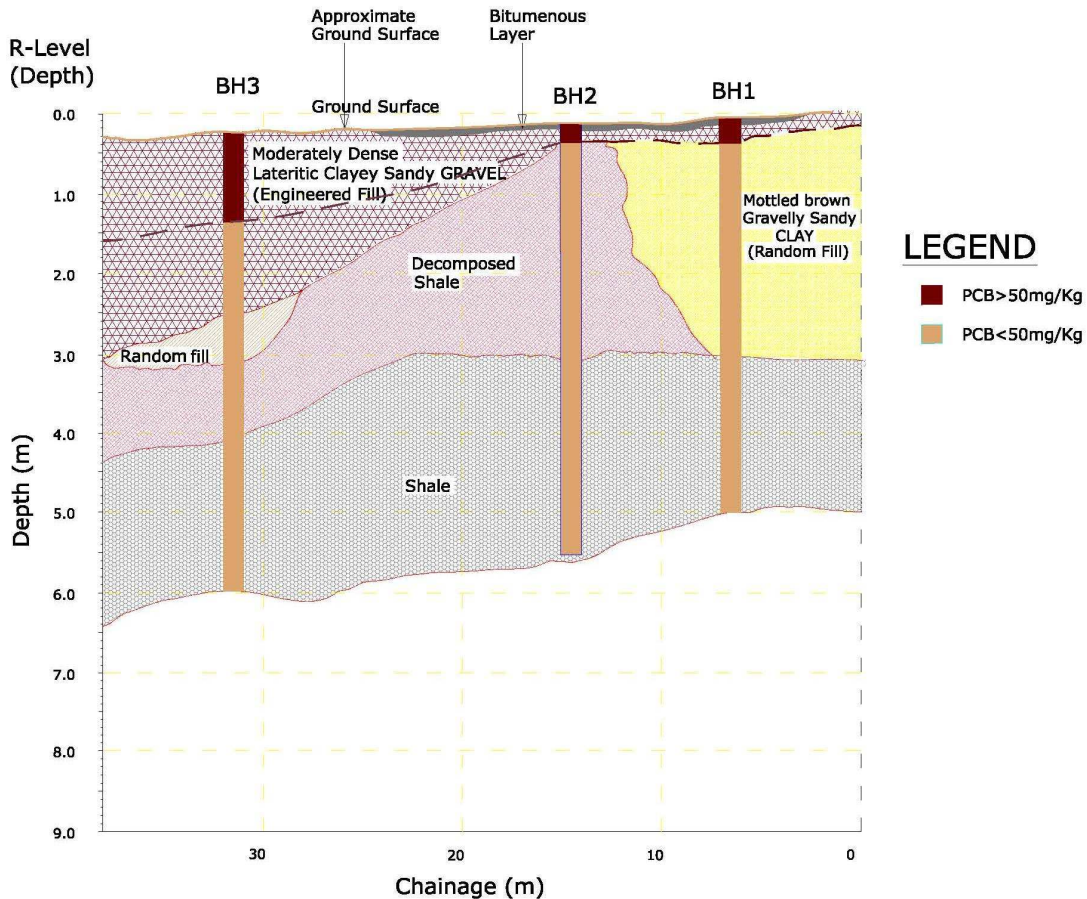
Figure G3.4
Cross-section of the soil profile of the study site

Hydrology and Drainage

The mean annual rainfall varies between 800 mm near the coast to about 1,270 mm close to the foothills of the Akwapim Range. Rainfall is measured on a number of gauges within the city but the principal rain gauge for the analyses of storms in the city of Accra is located at the Kotoka International Airport, which has daily recorded rainfall data since 1901 and autographic data since 1939. Frequency analysis has been carried out for the annual maximum series of rainfall durations of 1 h to 6 h and one day to three days, for return periods from 1999 to 2008, thus facilitating the development of the following rainfall intensity duration frequency (IDF) relationships for the city of Accra (see the PSI Stage 2 report).

Groundwater

Although groundwater was not generally encountered in the boreholes, except seepage that made some of the recovered soil samples very wet, groundwater levels were recorded in all boreholes after 24 hours, with a stabilized level at 0.74 m in BH1 and at 2.11 m in BH2. It is important to point out, however, that the investigations were carried out in the minor rainy

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season when groundwater levels are expected to be rising. It is quite conceivable that, given the subsurface conditions revealed by the investigations, namely a relatively impermeable weathered shale zone underlying relatively more permeable surficial soils, perched water tables could form during particularly wet seasons. Thus it was clear that one of these perched groundwater tables supplied a rising water table in the borehole. The minimum depth of water wells sunk so far within the Accraian rocks is known to be in the range of 30 m below existing ground level. Almost daily monitoring of the groundwater levels in the boreholes over a one-month period from the end of October to the end of November 2009 showed little change in the stabilized water levels in spite of isolated rainfall over the period. This is clearly indicative of the effectiveness of the shale layer in reducing the rate of infiltration down to the water table.

4 CONTAMINANT TRANSPORT IN POROUS MEDIA

Permeability (or hydraulic conductivity) of soils and rocks constitutes the most important criterion for evaluating not only the rate and spatial extent of contaminant transport in soils and rocks, but also the adequacy of hazardous waste depositories or installations. Many regulatory agencies specify that liners for hazardous waste sites should not have permeabilities higher than 10 cm/s. Yet, hydraulic conductivity is one of the most variable of soil parameters. Several factors influence the hydraulic conductivity of these materials. The hydraulic conductivity values determined in situ are more valid than those determined in the laboratory since they take account of the effects of the macrostructure of the soil or rock. Actual rates of leakage from ponds lined with clay exceed those that are predicted on the basis of permeability determined from laboratory tests. The relatively large ratios (10 and 1,000 times) between actual- and laboratory-determined permeabilities may be due to difficulties associated with obtaining "representative" laboratory samples containing a realistic distribution of desiccation cracks, fissures, slicken-sides, and other hydraulic defects typical of natural clay liners.

Another possible source of discrepancy between computed and actual hydraulic conductivities of soils and rocks is the fact that recent studies have established that clays can be markedly more permeable to concentrated organic fluids than to pure water, which is used in conventional field and laboratory hydraulic conductivity tests.

The hydraulic conductivity of partially saturated soils is generally much greater than the hydraulic conductivity of the same soils in the saturated state. The hydraulic conductivity of clay increases by as much as three orders of magnitude when the degree of saturation increases from below 50% to almost 100%. The existence and thickness of an unsaturated, moderately dense compacted lateritic fill zone in the surficial soils and the underlying shale is therefore an important factor in protecting the aquifer from PCB contamination.

5 MECHANISM OF CONTAMINANT TRANSPORT IN SOIL

Depending on whether it is miscible or immiscible in water, a contaminant introduced into an aquifer from a polluting source may either remain intact or mix with (and be diluted by) the water. It has been established that the rate of contaminant migration through unsaturated soils is much slower than the rate of migration in saturated media; hence the existence of a

substantial thickness of unsaturated soil between the polluting source and the aquifer is an added protection to the aquifer.

The attenuation capacity of soils to pollutants is based on the following four mechanisms:
- biological processes based on the purifying capacity of soil due to the action of bacteria and fungi in the soil on some of the harmful constituents of the pollutant
- physical processes involving the filtration of suspended impurities in the contaminant as it passes through the soil
- chemical processes that may involve reaction between substances in the contaminant and minerals in the soil
- dilution and dispersion in which the concentration of the pollutant is reduced because of its dilution with the groundwater

The resultant effect of the above attenuation properties is that the concentration of the pollutant reduces considerably with distance from the source.

The results of the PCB analyses conducted in this DSI are presented in Table G3.2. Some of the soils sampled from the boreholes recorded values exceeding the the Tier 1 Screening Level of Table 3.1 of Module 3 (AENV, 1009a) of 33 mg/kg used in this study, with the exception of the second borehole. BH1-1 gave a value of 65.130 mg/kg, representing contamination approximately two times greater than the the Tier 1 Screening Level. Samples taken from BH3-2 recorded 74.855 mg/kg. This value is approximately 2.26 times greater than the guideline value. Moreover, the total concentration of PCBs detected in the entire profiles of BH1 and BH3 shows contamination (Table G3.2). Oil spillage from the transformer maintenance workshop, which is close to BH1, could account for the high level of PCB concentration at that location. The moderately dense lateritic clayey sandy gravel (engineered fill) thickens sharply between BH2 and BH3, thus promoting the probable migration of contaminant from BH1 to BH3. Abandoned transformers awaiting disposal close to BH3 might have contributed to the high levels of PCBs in that location.

The observed soil profiles and levels of contamination (Figure G3.6) are described as follows:

BH1
- BH1-1 and BH1-2 are composed of the laterite region ranging from 0.15 m to 0.85 m. This region gave a PCB concentration of 82.256 mg/kg, indicating a contaminated zone.
- BH1-3 to BH1-5, composed of mottled brown gravelly sandy clay (1.2 m to 3 m), gave a PCB concentration of 3.842 mg/kg.
- BH1-6 and BH1-7, consisting of shale (3.2 m to 4.0 m), gave a PCB concentration of 7.762 mg/kg.

BH2
- BH2-1 and BH2-2, made up of laterite (0 m to 0.5 m), gave a PCB concentration of 2.837 mg/kg.
- BH2-3 to BH2-5, composed of decomposed shale (0.86 m to 2.5 m), recorded a PCB concentration of 3.033 mg/kg.
- BH2-6 and BH2-7, made of shale (3.4 m to 4.5 m), gave a PCB concentration of 0.859 mg/kg.

Table G3.2
PCB Concentration (mg/kg) in Boreholes Soil Profile

Sample ID	Depth (m)	PCB concentration	Applicable Standard	Exceeded ??
BH1	<0.3	65.130	33	Contaminated
	0.55-0.85	17.127	33	clean
	1.2-1.5	2.266	33	clean
	2.0-2.3	0.963	33	clean
	2.7-3.0	0.614	33	clean
	3.2-3.5	2.577	33	clean
	3.7-4.0	5.188	33	clean
BH2	<0.15	2.526	33	clean
	0.15-0.48	0.311	33	clean
	0.86-1.2	0.373	33	clean
	1.7-1.9	1.191	33	clean
	2.1-2.5	1.469	33	clean
	3.43-3.86	0.282	33	clean
	4.2-4.45	0.578	33	clean
BH3	0.3-0.45	3.744	33	clean
	0.75-1.22	74.855	33	contaminated
	1.56-1.65	6.133	33	clean
	1.91-2.07	31.015	33	clean
	2.32-2.45	9.054	33	clean
	2.8-3.0	5.158	33	clean
	3.25-3.54	1.811	33	clean
	3.83-4.02	0.932	33	clean
	4.57-4.79	0.793	33	clean
	5.13-5.29	0.512	33	clean
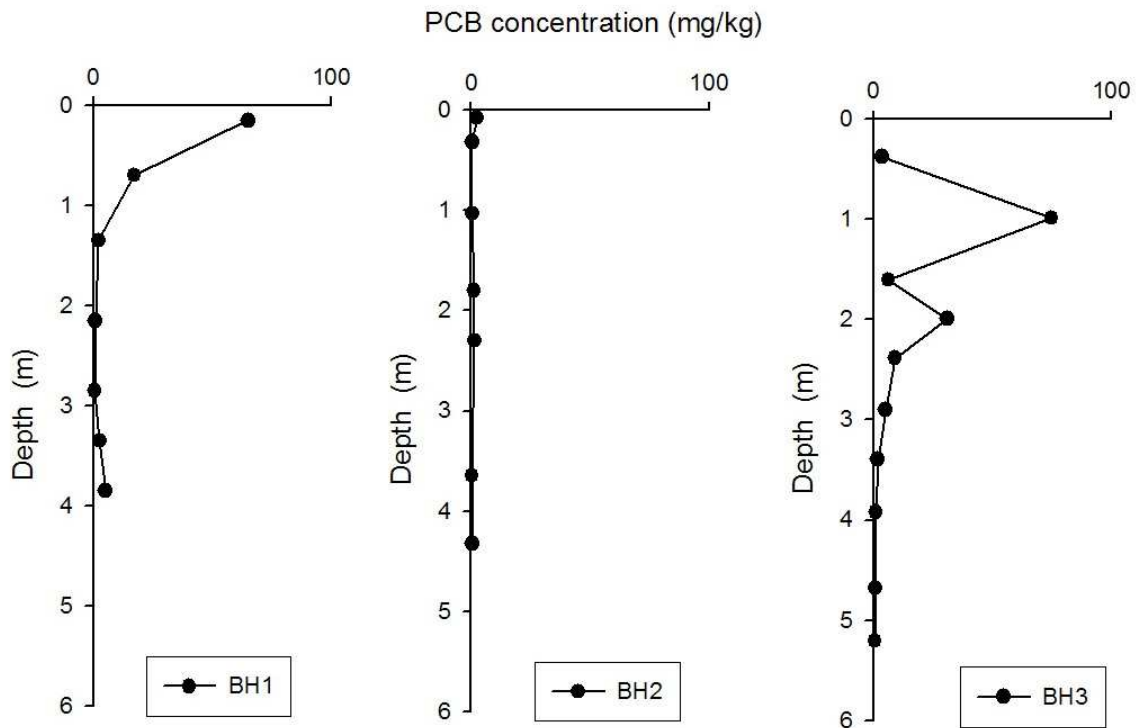
Figure G3.6
PCB contamination profiles for boreholes BH1, BH2 and BH3

BH3

- BH3-1 to BH3-6, the laterite region ranging from 0.3 m to 3 m, recorded a PCB concentration of 129.959 mg/kg.
- BH3-7 and BH3-8, the decomposed shale region ranging from 3.2 m to 4.3 m, gave a PCB concentration of 2.743 mg/kg.
- BH3-9 and BH3-10, made of shale (4.3 m to 6 m), recorded PCB concentration levels of 1.305 mg/kg.

The variably low levels of PCB concentration detected between the decomposed shale and shale regions, as shown in Figures G3.6, G3.7 and G3.8, could be attributed to the fact that the percolation of POPs, particularly PCBs, is restricted to the clay region. The high adsorption capacity of clay could serve as a saturation zone for the prevention of contaminant migration beyond this region. Moreover, it is established that the rate of contaminant migration through unsaturated soils is much slower than the rate of migration in saturated media. Therefore, the existence of a substantially thick unsaturated soil in the study area could account for low levels of movement of the contaminant along the profile of the boreholes sampled.

Table G3.3 shows levels of PCBs in borehole water sampled from BH1 which are comparing against the Tier 1 Screening Level of Table 3.2 of Module 3 (AENV, 1009a). Low levels of PCB contamination were detected in this borehole. This is in accordance with the fact that PCBs have low water solubility. Additionally, the existence and thickness of an unsaturated moderately dense compacted lateritic fill zone in the surficial soils and the underlying shale is therefore an important factor in protecting the aquifer from PCB contamination.

Table G3.3
Groundwater analysis from BH1

Sample Type	Sample ID	PCB Concentration (mg/L)	Applicable Standard (mg/L)	Exceeded?
1st water sample	BHW-1	**0.059**	**0.0094**	**Contaminated**
2nd water sample	BHW-2	**0.071**	**0.0094**	**Contaminated**

6 CONCLUSION

The results of this DSI have confirmed the conclusion from the PSI Stage 2 report, which indicated possible PCB subsurface contamination at the site. The shale region, together with the thick unsaturated moderately-dense compacted lateritic fill zone, which serves as a natural barrier in protecting the aquifer from PCB contamination, was found to contain high concentrations of PCBs. Possible migration of PCBs would therefore be from BH1 to BH3, in the direction of the Makola Market. The probably source of the PCB contamination is the transformer servicing workshop.

8   RECOMMENDATIONS

The lack of historical background, the finding that records regarding the facility are poorly kept, as well as the inadequate and inconsistent responses from the personnel interviewed, meant that there was very little reliable information which could be used to develop a sampling strategy for PSI-S2. This lack of key information had a negative effect on the

present DSI. If the site is to be developed for a shopping mall, it is vitally important to find the extent of contamination by PCBs and by other contaminants of concern. Therefore, it is recommended that a comprehensive surficial sampling (i.e. PSI Stage 2) be performed. Based on the additional surface sample results, the investigator can then decide whether or not further action is needed. (The procedures suggested in Modules 2 and 3 of this Toolkit should be followed.)

9.   LIMITATIONS OF THE REPORT

The congested nature of the site made fieldwork difficult at times. It was not easy for the geotechnical and topographical survey teams to move around due to the haphazard parking of vehicles, and the presence and placement of old transformers and other equipment. In addition, the existence of a network of high-density, high-voltage buried electrical services hindered the geophysical survey.

It must be noted that this work was conducted for training purposes, with significant time and budget restraints. Although the participants followed the procedures outlined in Module 2, it is likely that some cross-contamination occurred due to the inexperience of the participants and inadequate support. Due to the limited analytical capability, only seven congeners of the 20 or more usually identified were determined in this study. In addition, note that the results of this work only reflect the date of sampling, i.e. the period between October 14 and 16, 2009.

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A.) REQUIRED MATERIALS			
Personal Protection Equipment	OK	NA	Units
• Chemical protective clothing category III for high risk	OK		
• Fall protection equipment		NA	
• Reflecting vest and/or other visibility reflecting accessories		NA	
• Face masks		NA	
• Full face mask respirator and mask filters (against organic vapours and toxic particles)		NA	
• Safety helmet		NA	
• Shatterproof safety glasses	OK		
• Hearing protection	OK		
• Work gloves and single-use nitrile gloves	OK		
• Safety boots		NA	
• Overshoes/Overboots	OK		
Collective protection equipment	OK	NA	Units
• First aid kit		NA	
• Emergency showers		NA	
• Eye wash cleaning water		NA	
• Autonomous oxygen supply		NA	
• Fire extinguisher		NA	
• Detection devices (for fumes, gases, etc.)		NA	
• Absorbent paper		NA	
Drilling machine	OK	NA	Units
• Drill pipes	OK		2
• Drill crowns	OK		
• PVC pipe	OK		
• Slotted pipe	OK		
• Stopper	OK		
• Pipe cap	OK		
• Gravel		NA	
• Cement	OK		2
• Bentonite	OK		2
• Cover	OK		4
Equipment for soil-gas, hydraulic conductivity and sampling activities	OK	NA	Units
• Hand auger equipment		NA	
• PID (Photoionization detector)		NA	
• Teflon tube		NA	
• Freezing bags	OK		
• Explosimeter		NA	
• pH meter		NA	
• Conductivity and temperature meter		NA	
• Redox meter		NA	
• Dissolved oxygen meter I		NA	
• Interphase probe		NA	
• Bailers (minibailers)		NA	
• Pumps (minipurgers)	OK		1
• Cool boxes	OK		2
• Soil sample bags	OK		100
• Water sample bottles (containers)	OK		12
• Adhesive labels for sample bags	OK		
Geophysical works	OK	NA	Units
• Geophysical gear		NA	

	OK	NA	Units
• Laptop and its charger		NA	
• Data registry and storage system		NA	
• Extension cord		NA	
• Adapters		NA	
• Wire coils		NA	
• Network cable		NA	
• Probe or small measurement device	OK		2
• Electric winch		NA	
• Junction cable between probe and data registry/storage equipment		NA	
• Voltmeter to check connections		NA	
Other materials	OK	NA	Units
• Toolbox	OK		
• Geological hammer	OK		
• Allen wrench		NA	
• Screwdrivers		NA	
• Mallet		NA	
• Pliers		NA	
• Compass/GPS (Geographical Positioning System)	OK		2
• Spray or paint for marking		NA	
• Insulating tape		NA	
• Packaging tape		NA	
• Tape measure	OK		
• Photo camera	OK		
• Notebook & pen	OK		
• Edding		NA	
• Cutter		NA	
• Scissors		NA	
• Penknife		NA	
• String	OK		
• Lantern		NA	

B.) HEALTH AND SAFETY MEASURES	OK	NA
• Is there an approved Health and Safety Plan?	OK	
• Has every member of the team been instructed about the Health and Safety Plan?	OK	
• Have affected people/organizations been warned about the works?		NA
• Can all the Health and Safety Plan requirements be fulfilled?	OK	
C.) ENVIRONMENTAL SITE ASSESSMENT		
C.1.) Soil gas analysis	OK	NA
• Performance of a utility survey	OK	
• Determination of distribution of soil gas investigation points		NA
• Determination of sampling depth	OK	
• Pre-drilling	OK	
• Drilling of boreholes	OK	
• Soil gas sample collection		NA
• Field analysis of soil gas samples		NA
• Laboratory analysis of soil gas samples		NA
C.2.) Application of geophysical methods	OK	NA
• Design for establishing the position of soil profiles to be analyzed	OK	
• Determination of direction and length of soil profiles to be analyzed	OK	
• Determination of number of soil profiles to be analyzed	OK	
• Determination of separation between soil profiles to be analyzed	OK	
• Determination of separation between measurement points	OK	
• Taking measurements	OK	
C.3.) Drilling of soil borings	OK	NA
• Location of soil borings	OK	
• Design of soil borings distribution in the study area	OK	
• Sign exact sampling points with painting/spray		NA
• Execution of soil borings (for each drilling location)	OK	
• Performance of utility survey	OK	
• Drilling of localization soil borings (3-4 m depth)	OK	
• Drilling of investigation soil borings (more than 4-5 m depth)	OK	
• Filling of each hole with grout to ground surface after conclusion of each soil boring		NA
Collection of the following information during drilling works		
• Name or identification number of soil boring	OK	
• Start and end date of works	OK	
• Observed lithology		NA
• Soil appearance and colour	OK	
• Presence of humidity		NA
• Water levels and non-aqueous phase liquid levels	OK	
• Drilling company	OK	
• Drilling typology	OK	
• Boring depth	OK	
• Drilling device diameter	OK	
• Collected samples, with relative sampling depth and identification code	OK	
• Stratigraphy, with possible visual exam notes	OK	
• Taking photographs of samples and sample locations	OK	

	OK	NA
C.4.) Installation of monitoring wells	**OK**	**NA**
• Completion of strategic investigation soil borings as monitoring wells installing piezometers	OK	
• Well development and purging until the water runs clear and physicochemical parameters are stable	OK	
Measurement of the following parameters prior, during and after well development		
• Static water level	OK	
• Groundwater presence and level	OK	
• Water colour	OK	
• Turbidity		NA
• Odour		NA
• pH		NA
• Temperature		NA
• Specific conductance		NA
• Presence of non-aqueous phase liquid (NAPL)		NA
Recording of data related to well installation activities, specifying:		
– Piezometer identification number		NA
– Measurement data	OK	
– Piezometer depth		NA
– Piezometer location coordinates		NA
– Supervision of monitoring well installations by specialists	OK	
C.5.) Topographic survey	**OK**	**NA**
• Measurement of X,Y,Z coordinates of each soil borehole, groundwater monitoring well and trial pit by means of a GPS	OK	
C.6.) Hydraulic conductivity tests	**OK**	**NA**
• Performance of slug tests, either adding or removing a measured quantity of water from monitoring wells		NA
• Rapid water-level measurements at regular time intervals	OK	
C.7.) Sampling activities	**OK**	**NA**
Soil sampling:		
• Extraction of soil core samples and placement in core boxes	OK	
• Checking for the presence of any visual of olfactory evidence of contamination during drilling operation	OK	
• Use of PID (Photoionization Detector) for rapid field sample analysis		NA
• Correct classification of soil samples taking into account parameters as soil type, colour, grain size distribution, textural changes, etc	OK	
• Selection of representative samples	OK	
• Soil sample preparation and placement into containers	OK	
• Labelling of soil sample containers	OK	
• Storage of soil sample containers at low temperatures (4ºC) and in the dark	OK	
• Sending of soil sample containers in refrigerated or thermo-insulated boxes to the laboratory in 24-48 hours	OK	
• Completion of Chain of Custody including for each sample the same information reported on its label	OK	
• Taking photographs at sampling locations and of soil samples	OK	
Groundwater sampling:		
• Collection of groundwater samples from monitoring wells after well development		NA
• Collection of water samples directly into appropriate containers		NA
• Labelling of water sample containers		NA
• Storage of water samples at low temperatures (4ºC) and in the dark		NA
• Sending of water samples to the laboratory in refrigerated or thermo-insulated boxes in 24-48 hours		NA
• Taking photographs at sampling locations and of water samples		NA

D.) ENVIRONMENTAL SITE MONITORING IN THE FIELD		
Groundwater contamination control through monitoring wells:	**OK**	**NA**
• Design of a strategic monitoring network: determination of optimal location and number of piezometers		**NA**
• Design of a monitoring program, including:		
– Frequency of groundwater level measurements	**OK**	
– Frequency of groundwater sample collection		**NA**
– Water sample analysis types		

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Section	Checklist	Status Yes/No (Y/N)
SUMMARY *Important information*	1. Does the investigator: a) identify who the major participants are in the investigation; b) provide important facts and study results at the beginning of the report; c) provide a clear understanding of the data contained within the body of the report; and d) discuss the results of any preliminary site investigations?	Y Y Y Y
Sampling information	2. Does the summary: a) state how representative the sampling pattern and analysis is of property soil conditions; b) specify the probabilities of false positive and false negative answers; c) identify what the chemical analysis program focused on; and d) indicate how reliable the sampling methodology and laboratory analysis was?	Y N Y Y
OBJECTIVES *Goals*	3. Are the goals of the investigation: a) clearly stated; b) in compliance with the scope of work agreed upon with the client; and c) consistent with ministry goals and objectives?	Y Y Y
SITE HISTORY & DESCRIPTION *Description of the site*	4. Has the investigator: a) specified the dates when site visits were conducted; . b) provided a site map, including land use, relevant buildings found on site, dimensions in metres and area of the property in hectares; c) included natural features such as lakes, rivers, streams found at least partially within the boundaries of the property; d) included constructed features such as, underground storage tanks, lagoons, ditches, sumps within buildings, and waste storage areas; e) provided a reasonable substitute if no site map is available; f) provided an area topographic map of 1: 20 000 or larger; and g) included a scaled aerial photograph of the site and adjacent environs?	Y Y Y Y N Y Y
Climatic conditions	5. For DSIs are: a) annual precipitation records provided; b) along with a description of seasonal variations in precipitation; and c) estimates of infiltration rates provided?	Y Y Y
Groundwater	6. Has: a) the depth to groundwater from the ground surface and the depth and thickness of multiple aquifers been calculated; b) seasonal groundwater fluctuation been documented; c) the lithology and vertical permeability of the unsaturated zone been described; and d) the stratigraphy, structure, geometry, porosity, hydraulic conductivity, storage properties, transmissivity, and groundwater flow direction of the saturated zone been described?	Y Y Y Y
Wells	7. If monitoring wells have been installed near the disposal areas previous to this investigation, a) have the monitoring results been reviewed; b) have data been included that indicate why and when a monitoring well was installed and by whom; and c) has any previous geotechnical investigative work been identified and reviewed?	 N N N

Soil types and soil depths	8. Has the investigator: a) provided soil survey information at a scale of 1:20 000 or larger; b) contacted soil survey personnel, or local soil scientists; c) provided an on-site map and appropriate cross-sections showing soil types, soil depth and other soil parameters that may be related to location and extent of contaminants; and d) shown the relationship between groundwater and soil in the cross-sections?	Y Y Y Y
Basic preliminary information about liability	9. Does the investigator: a) provide adequate information about any court or administrative actions, ministry orders, Federal charges under the *Fisheries Act* etc., orders; and b) surmise whether there will be any potential litigation in this case?	N N
DATA *Goals of the study*	10. Has the investigator discussed the following about the goals of the study: a) what are the goals of the detailed site investigation; b) will analysis of the populations identified in the study lead to achieving these goals; and c) are the goals extensive enough to identify the Area(s) of Environmental Concern (AEC)?	 Y Y Y
Populations	11. For detailed site investigations has the investigator: a) used historical and other preliminary site investigation information to help delineate separate populations; b) attempted to identify how many contaminant distributions there are; and c) attempted to identify background levels in the surrounding area for contaminants that occur naturally or that may have been deposited by non-point sources?	 Y Y Y
Plans	12. For detailed site investigations: a) does the investigator explain the rationale behind the sampling plan; b) does the sampling plan reflect the potential sources, pathways, and receptors of contaminants; c) does the plan reduce the potential of type I and type II errors; d) has the investigator over-sampled to compensate for invalidated results (broken bags, lost labels, etc.); e) has the investigator avoided collecting composite samples for preliminary site investigations; f) has the investigator provided a rationale for using composites or a combination of composite and discrete samples; g) has the investigator detailed the procedures used to collect, record, confirm and verify the database; h) does the investigator provide an adequate location of each sample (e.g., has the sample grid been tied into UTM co-ordinates); i) has the investigator determined the background soil conditions for the parameters being investigated; and j) does the investigator provide a rationale for choosing the area used to represent ambient conditions?	Y Y Y N Y Y Y Y Y Y
	13. If previous studies have been used in the detailed site investigation: a) have the data been summarized and presented in the report; b) have the data been used to add to the density of sampling locations; c) has the source of additional data been identified and its use justified; and d) has the investigator given reasons for including or excluding data from previous studies?	 N N N N

	14. Has the investigator: a) used a regular grid with a randomly located origin to estimate contaminant distribution in non-areas of environmental concern (non-AECs); b) collected the number of samples needed to conform with the level of confidence require to establish contaminant levels in non-AECs; and c) used the coefficient of variation to determine if non-AECs have been unaffected by local AECs?	Y Y Y
	15. For the sampling plan has the investigator: a) oriented the sample grid in the direction (if known) of flow of the pollutant, which may relate to site topography or wind direction; b) selected random samples, locations and/or starting points using procedures based on uniform random numbers; and c) included a random number table?	Y Y N
	16. For the detailed site investigation of stockpiles has the investigator: a) designed a sampling program that ensures a fair representation of the contaminant concentrations in the entire pile; b) based the stockpile classification on at least five separate analyses; and c) determined if the material within the pile is sufficiently homogenous to warrant classifying the entire under a single classification?	Y Y Y
	17. For investigations of groundwater: a) has the investigator used any groundwater data available from preliminary site investigations; b) have at least 3 monitoring wells been used with at least one located up-gradient of groundwater flow; .. c) have samples been collected at least 24 hours after the development of a well; d) have groundwater samples been collected after wells have been purged; and e) has integrity testing of underground storage tanks near sensitive receptors such as potable water supplies been carried out?	N Y N N N

Protocol	18.	Has the investigator: a) included the original quality assurance plan; b) run a complete check of all data against original records; c) provided documentation of reliability of any data that is significant to the study's conclusions; d) shown that that no systematic bias has been used during the sampling procedure, including collection, preparation and analysis; e) shown that the analytical methods used for all samples are acceptable to the ministry; f) used control charts to monitor and control the accuracy and precision of the analyses for large studies with more than 100 samples; g) used a t-test to determine whether the average of repeat analyses is significantly different from the established reference value; h) used paired analyses of duplicates of the same material especially where suspected contaminant levels are believed to be at their highest concentrations; i) shown that paired analyses of sample material split in the field shows a rank and linear correlation of 0.95 or greater for metallic and inorganic contaminants, and 0.90 or greater for organic contaminants; j) followed recommended ministry lab services QA/QC protocols; and k) documented any corrective action taken if QA/QC reveals significant bias or high imprecision?	Y Y Y Y Y Y Y N N Y Y
	19.	For AECs: a) has the investigator ensured that the spacing between samples is smaller than the range of correlation; and b) has the investigator used multi-stage sampling plans to detect and identify the extent of hot spots, including fine grids and step-outs?	Y Y
EXPLORATORY DATA ANALYSES *Non-parametric method*	20.	For detailed site investigations, has the investigator: a) made all distribution assumptions explicit in the report; b) used non-parametric methods to show data that is not normally distributed; c) used percentile-based statistics, such as quartiles and the median, to supplement the more traditional mean and standard deviation; and d) used box plots as an alternative to histograms especially when comparing two or more groups of data?	Y Y Y N
Univariate descriptions	21.	For univariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; c) made use of graphical representations of the data, such as histograms, or probability plots; d) used summary statistics that describe the centre, location, spread, and shape of the univariate distribution; and e) used logarithmic scaling, if the data are skewed, to make graphical presentations more informative?	Y Y Y Y Y
Bivariate Descriptions	22.	For bivariate distributions, has the investigator: a) made all distribution assumptions explicit in the report; b) documented the integrity of the data; and c) used scatter plots that display the relationship between pairs of variables and linear and rank correlation coefficients that summarize the strength of the relationship?	Y Y Y

Spatial Description	23.	Has the investigator used: a) contour maps and cross-sections to show spatial distribution of contaminants;	N
		b) graphical displays that present the available data in their spatial context;	Y
		c) sample values for data on maps or cross-sections;	N
		d) colours, grey scales, or symbols to high-light the locations of the highest sample values;	N
		e) kriging for the purpose of interpolation and not extrapolation; and	N
		f) quadrants or other forms of local statistics to assist the reader in understanding and evaluating decisions about statistical populations and trends?	N
Outliers	24.	For all distributions has the investigator: a) used rank correlation as an alternative to linear correlation to reduce sensitivity to outliers when summarizing the relationship between two variables;	N
		b) used probability plots, scatter plots and data postings to identify outliers;	Y
		c) determined whether the existence of outliers requires that any critical assumptions need to be modified;	N
		d) determined the reasons for the existence of the outlier;	N
		e) documented the reasons for and provided all relevant information about any outlier value that has been discarded; and	N
		f) taken a new sample at a random location within one metre of a discarded outlier sample?	N
STATISTICAL ANALYSIS AND INTERPRETATION *Assumptions*	25.	Has the investigator a) described the statistical tools and procedures used to analyze and interpret the data along with their underlying assumptions;	Y
		b) included calculations and assumptions for population standard deviations estimated for the purposes of a confidence interval calculation;	Y
		c) provided rationale for method used to deal with non-detectable data;	Y
		d) used a nonparametric alternative as a way of checking the sensitivity of the conclusion to the distribution assumption; and	Y
		e) included a statement about the uncertainty of all estimated or predicted values?	Y
Calculations	26.	Has the investigator: a) calculated percentiles in normal, lognormal or exponential distribution models; and	N
		b) described how percentiles were calculated?	N
Probability maps	27.	Have probability maps been included to show that there is less than a 5% chance of making a false negative error about the quality of material?	N
CONCLUSIONS AND RECOMMENDATIONS *Conclusions*	28.	Has the investigator: a) provided clear and unambiguous conclusions with specific references to the analysis and interpretations that support them;	Y
		b) accompanied each conclusion with a discussion of how it is affected by any underlying assumptions, by the accuracy and precision of the available sample data and by the uncertainty in estimated or predicted values;	Y
		c) classified material based on the data being demonstrably representative of one population; and, for that data set: the upper 90th percentile of the sample concentrations is less than the criterion concentration; and the upper 95 per cent confidence limit of the average concentration of the samples is less than the criterion concentration; and no sample within the data set has a concentration exceeding two times the criterion concentration?	Y

Recommendations	29.	Has the investigator: d) provided clear and unambiguous recommendations; e) informed the client of any other issues of potential concern outside of the goals of the study; and f) provided a rationale with any recommendations, for further investigation?	Y N Y
REFERENCES *Complete Information*	30.	Has the investigator referenced: a) all data sources, previous studies and other sources (including interviews) that contributed information to the study; and b) any technical literature that provides additional detail on procedures used in the study?	Y Y
APPENDICES ***QA/QC***	31.	Has the investigator provided: a) analytical laboratory results, either in printed form or on a diskette (Excel preferred) (mandatory requirement); b) laboratory QA/QC procedures, sampling protocol and the results of check analyses (mandatory requirement); c) drill logs and test pit logs (mandatory requirement); and d) a site map showing sampling locations (mandatory requirement)?	Y Y Y Y
Documentation	32.	Has the investigator included: a) details of statistical computations omitted from the main body of the report; and b) the name and version of the computer software used for the database compilation and the statistical analysis, or a brief description and a reference for any other non-commercial software used in the study?	Y Y

MODULE 3

ASSESSING SITE RISKS

This module provides guidelines for assessing the human health risks of sites contaminated by persistent organic pollutants.

It outlines how to conduct a generic Tier 1 approach, in which you use the information collected during the site investigation to compare contaminant concentrations against the recommended values for soil and groundwater.

This module also presents the basic steps of a Site-Specific Risk Assessment, which identifies a site's contaminants, exposure pathways and receptors. You can then use this as the basis for developing a risk management process in situations when complete remediation is not a viable option for a contaminated site.

3.1 INTRODUCTION

The principal objective of this module is to establish acceptable guidelines for assessing the risks associated with a site contaminated by persistent organic pollutants (POPs). These guidelines also describe a process whereby owners/operators of contaminated sites and regulatory authorities have common ground to assess a site to ensure that human health and safety are well protected.

After site investigation and characterization as stated in Module 2, Module 3 guides you step-by-step to assess risks of POP-contaminated sites. Based on the site characteristics (see Module 2), you must first perform a Tier 1 assessment (sections 3.3 and 3.4) as outlined in this module as a general assessment of a site, to evaluate the risks to human beings and the environment. The screening levels for soil and groundwater are summarized and provided in Tables, to help you compare contaminant concentrations at the site with recommended values, compiled from different available sources.[1] If contaminant concentrations exceed the recommended values, i.e. the site has significant risks, the user needs to consider whether a site cleanup is technically (Module 4) and economically (Module 5) viable. If not, the user might apply Site-Specific Risk Assessments to manage the site (i.e. Exposure Prevention), which might greatly reduce the overall remediation cost.

By means of a similar process, you can integrate environmental risk assessment using the three circles approach (section 2 of this Module) into contaminated site management by cutting off one the three risk components (as discussed in Module 4).

This Site-Specific Risk Assessment is intended to provide you with basic steps for site-specific assessment. Simple examples of calculations of health risk are also provided: they are intended to help you to understand the human risk calculation. Please bear in mind that detailed site-specific risk assessment is very complex, normally being carried out by specially trained "Risk Assessors".[2]

3.2 DEFINITION OF RISK ASSESSMENT

The U.S. Environmental Protection Agency (USEPA) [3] defines risk assessment as a qualitative or quantitative evaluation of the risk posed to human health and the environment due to the actual or potential presence of pollutants. Risk assessment involves the characterization of the nature, magnitude and likelihood of adverse effects on human health or ecosystems as a result of exposure to pollutants through various pathways.

Environmental risk assessments typically fall into one of two areas:
- human health risk assessments: the process of estimating the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, immediately or in the future
- ecological risk assessments: the process of evaluating how likely it is that the environment may suffer adverse impacts as a result of exposure to one or more

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[1] In preparing this module, technical literature and reports from various organizations have been surveyed. The value of the screening level of POPs and preliminary quantitative risk assessments summarized in this module are based on available information. See the reference list at the end of this toolkit for further details.

[2] For comprehensive risk management, you can visit website http://www.popstoolkit.com.

[3] USEPA 1989

environmental stressors such as chemicals, changes in land use, disease, invasive species or climate change

Risk assessment is a scientific process with risk depending on the following three components:
- contaminant: a substance with the potential to cause serious effects on an organism, ecosystem or environment
- exposure pathway: a route or series of routes or means by which a receptor can be exposed to a contaminant
- receptor: an individual or an ecological system that could be adversely affected by a contaminant

Figure 3.1 illustrates environmental risk as the overlapping region between contaminants, exposure pathways and receptors. Risk is expressed as the probability that the three components will overlap. If a risk is found to be probable, effects resulting from exposure may be eliminated by reducing the concentration of the contaminants to an acceptable level.
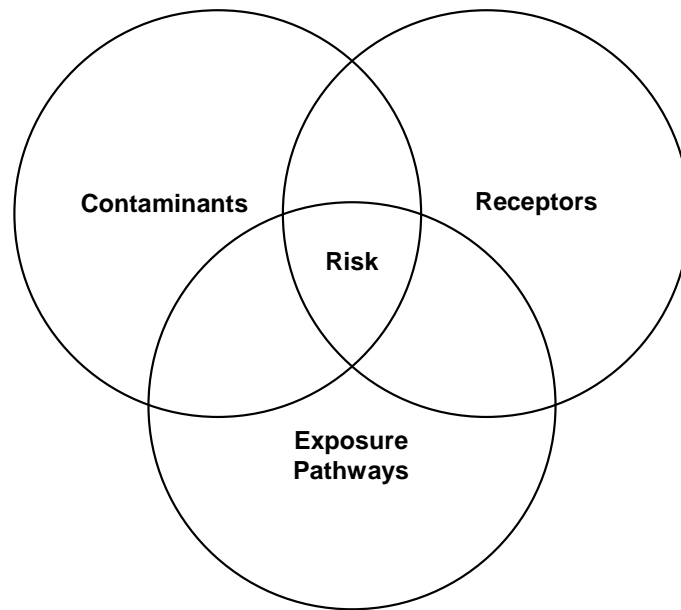
Figure 3.1
Environmental risk components

Figure 3.2 illustrates the various pathways by which an environmental contaminant can be distributed and reach its receptor. It is important to understand that contaminants pose no threat if there is no linkage with a receptor.
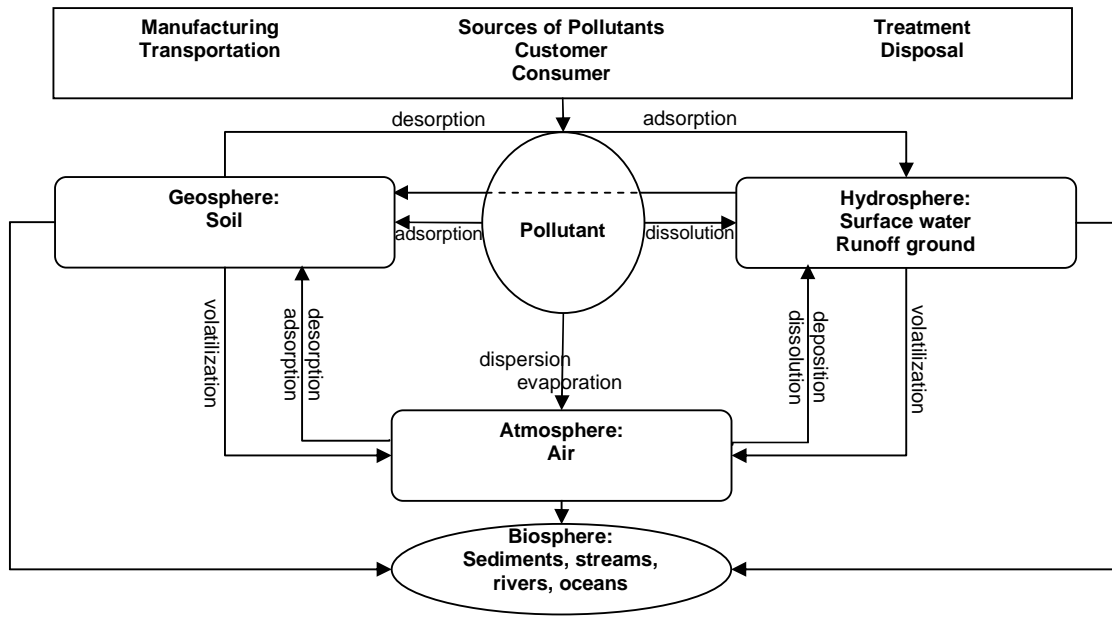
Figure 3.2
Pathways for distribution of environmental contamination

3.3   RISK ASSESSMENT OF POP CONTAMINATED SITES

There are two different approaches that can be taken to assess POP-contaminated sites: Tier 1 and Site-Specific Risk Assessments.

Tier 1 is a set of generic guidelines that provide simple tabular values that were developed based on conservative scientific assumptions about soil and groundwater characteristics. Two of the three risk assessment components, receptors and pathways, are already built into a Tier 1 assessment; therefore, only the contaminants need to be considered. Tier 1 assessments require minimal site-specific information and can be applied to most sites without modification. The need to apply professional judgment is minimal, and it is anticipated that application should be within the capabilities of all approved professionals. In particular, Tier 1 values may be helpful as simple guidelines for developing countries. It should be noted that when new and updated values on soil quality, drinking water, toxicological reference values, contaminant bioavailability, human characteristics and exposure factors, and other aspects of risk assessment are available, the criteria listed in Tier 1 should be revised accordingly.

Site-Specific Risk Assessments guidelines, however, require site-specific information that allows an assessor to develop guidelines that are tailored to the specific characteristics of an individual site, taking into account a range of factors. While this is a preferable approach to Tier 1 in many respects, considerably more work and professional training are required. The expertise for these complex assessments involves multidisciplinary experts including biologists, chemists, health sciences professionals and toxicologists trained in carrying out risk assessment related to contaminated site issues. At the present time, there are only a handful of qualified assessors in the world.

It is important to note that both Tier 1 and Site-Specific Risk Assessments are intended to assure human health. Neither assessment addresses environmental protection issues specifically (see section 3.5 of this module for a general treatment of these issues).

The process for implementing Tier 1 criteria to assess POP-contaminated sites is illustrated schematically by the flowchart in Figure 3.3, which also shows the interaction between the Tier 1 and Site-Specific Risk Assessment approaches.

If certain site conditions apply, the Tier 1 guidelines[4] may not be suitable and a Site-Specific Risk Assessment should be carried out. These conditions include the following:
- Groundwater flows to stagnant water bodies.
- Soil or groundwater contamination is present within 10 metres of a surface water body.
- The ground is composed of very coarse textured materials with high permeability (giving groundwater velocity $> 3x10^{-7}$ m/s or vapour permeability $>3x10^{-8}$ cm^2).
- There is contamination in fracture bedrock (fracture length exceeds 2 cm).
- There are organic soils.
- The contaminated source length parallel to groundwater flow is greater than 10 metres.

3.4   HOW TO CONDUCT A TIER 1 ASSESSMENT

There are four basic steps in a Tier 1 assessment with the first three based on the information gathered during the initial site characterization (as described in Module 2):
- identification of contaminants
- determination of the desired land use and soil type
- delineation of contamination extent
- application of Tier 1 values

Identification of Contaminants

 All contaminants (POPs) of concern that may be present at the site should be identified.

Determination of the Desired Land Use and Soil Type

Land use categories

The relevant land use categories are as follows:
- natural area: the area is remote from human habitation and activities
- agricultural: the primary activity is growing crops or tending livestock
- residential/parkland: the primary activities involve residential living and recreation uses.
- commercial: the primary activity is commercial (e.g., mall), and public access is not limited

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[4]   Detailed information can be obtained from the Alberta Tier 1 Soil and Groundwater Remediation Guidelines (AENV, 2009a).

- industrial: the primary activity is industrial in nature (e.g., manufacturing, utilities, bulk storage), and public access is controlled
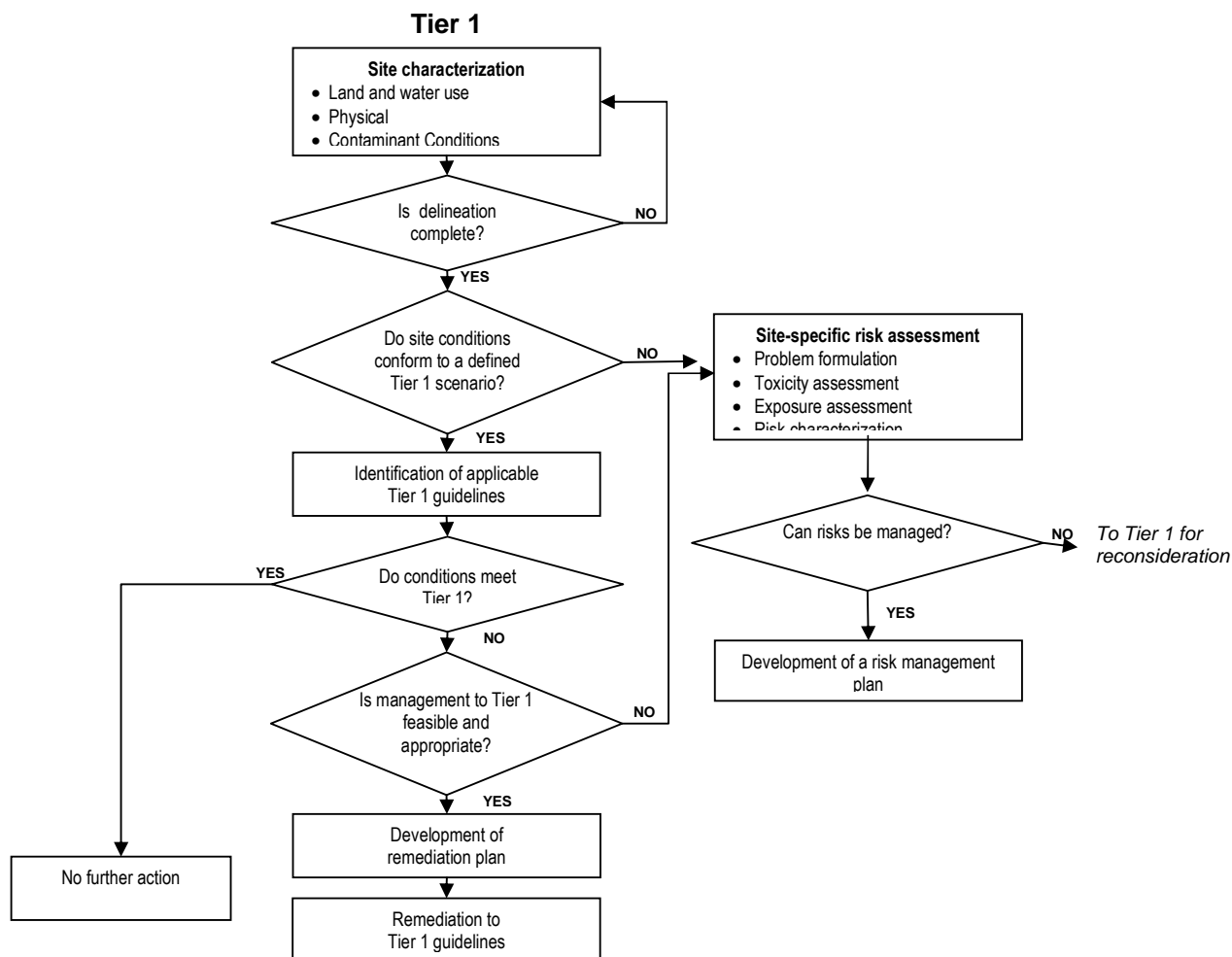
Tier 1

Figure 3.3
Implementation Framework for Tier 1 and Site-specific Risk Assessment

Soil type

Soils are classified according to particle size:

- coarse grain (bulk density = 1,700 kg/m^3, porosity $\approx$ 0.36)
- fine grain (bulk density = 1,400 kg/m^3, porosity $\approx$ 0.47)

Delineation of the Extent of Contamination

The size, depth and extent of contamination of the site must be identified including:
- the physical, chemical and biological properties; and
- the horizontal and vertical profiles of the contamination.

Application of Tier 1 Values

Using the data from the previous three steps, the most appropriate values can be selected from the Tier 1 value tables (see Table 3.1 for soil screening levels and Table 3.2 for those on groundwater). Please note that the data in these tables are not widely available, and have been extracted with great difficulty from various government Internet sources for the purposes of this Toolkit. A comparison can then made between the laboratory test results and the relevant table values to determine whether the contaminants are within acceptable criteria. If the contaminants are within acceptable ranges, the risk is considered minimum; if they exceed the table values, then remediation will be required to reduce or remove the risk to acceptable levels.

In certain situations, there may be technical, economic or environmental constraints that preclude the remediation option. In those cases, a Site-Specific Risk Assessment should be carried out in order to develop an alternative form of risk management for the site. These site management options involve the prevention of exposure to contamination (as explained in Module 4), which may, in the long term, greatly reduce the overall remediation cost.
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Table 3.1
Tier 1 Soil: Screening Levels

Soil Type	Fine					Coarse				
Land Use	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial
Unit	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Aldrin*	5.9	3.4	3.4	5.1	5.9	7.4	3.4	3.4	5.1	7.4
Chlordane**			0.44	1.7	1.7			0.44	1.7	1.7
Dichlorodiphenyltrichloroethane (DDT)*	0.015	0.015	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.018
Dieldrin*	0.011	0.011	0.011	0.011	0.011	0.014	0.014	0.014	0.014	0.014
Endrin*	0.0075	0.0075	0.0075	0.0075	0.0075	0.0090	0.0090	0.0090	0.0090	0.0090
Heptachlor**			0.013	0.013	0.013			0.013	0.013	0.013
Hexachlorobenzene*	3.6	0.8	3.6	3.6	3.6	7.0	0.5	0.5	6.0	6.0
Mirex***			0.031	0.12	0.12			0.031	0.12	0.12
Toxaphene*	3.3	3.3	3.3	3.3	3.3	6.3	4.8	4.8	6.3	6.3
Polychlorinated biphenyls (PCBs)*	1.3	1.3	22	33	33	1.3	1.3	22	33	33
Dioxins and Furans*	0.00025	0.000004	0.000004	0.000004	0.000004	0.00025	0.000004	0.000004	0.000004	0.000004

Source: * AENV 2009a, Table 1
      ** CRWQCB 2007, California Environmental Screening Level for Shallow Soil
      *** Cal/EPA 2005. California Human Health Screening Level

Table 3.2
Tier 1 Groundwater: Screening Level

Soil Type	Fine					Coarse				
Land Use	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial
Unit	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Aldrin**	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002
Chlordane**	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004
Dichlorodipheny-ltrichloroethane (DDT)*	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
Dieldrin*	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056	0.000056
Endrin*	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036	0.000036
Heptachlor**	0.0000036	0.0000036	0.0000036	0.0000036	0.0000036	0.0000036	0.0000036	0.0000036	0.0000036	0.0000036
Hexachloro-benzene*	0.00057	0.00057	0.00057	0.00057	0.00057	0.00057	0.00057	0.00057	0.00057	0.00057
Mirex***	0.0000000068	0.0000000068	0.0000000068	0.0000000068	0.0000000068	0.0000000068	0.0000000068	0.0000000068	0.0000000068	0.0000000068
Toxaphene*	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002	0.0000002
Polychlorinated biphenyls (PCBs)*	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094
Dioxins and Furans*	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012	0.00000012

Source: * AENV 2009a, Table 2
      ** CRWQCB 2007, Groundwater Screening Level
      *** MEDQ 2004, Attachment 1. Table 1

3.5 HOW TO CONDUCT A SITE SPECIFIC RISK ASSESSMENT

A Site-Specific Risk Assessment involves the following four basic steps:

- problem formulation
- toxicity assessment
- exposure assessment
- risk characterization

Problem Formulation

The problem formulation process, which defines the objectives and scope of the risk assessment, is based on the three environmental risk components — contaminants, exposure and receptors — highlighted in Figure 3.1 (section 3.2). It specifies the issues that must be evaluated. The parameters to be identified include:

- a qualitative evaluation of contaminant release, transport and fate
- identification of contaminants of concern
- identification of potential receptors
- identification of exposure pathways

The end-product is a conceptual model that includes sources of contaminants, routes of transport, contaminant media, routes of exposure, and endpoint receptors (USEPA, 1997). The model is often displayed in the form of a flow chart or a schematic, as shown in the Figure 3.4 example.
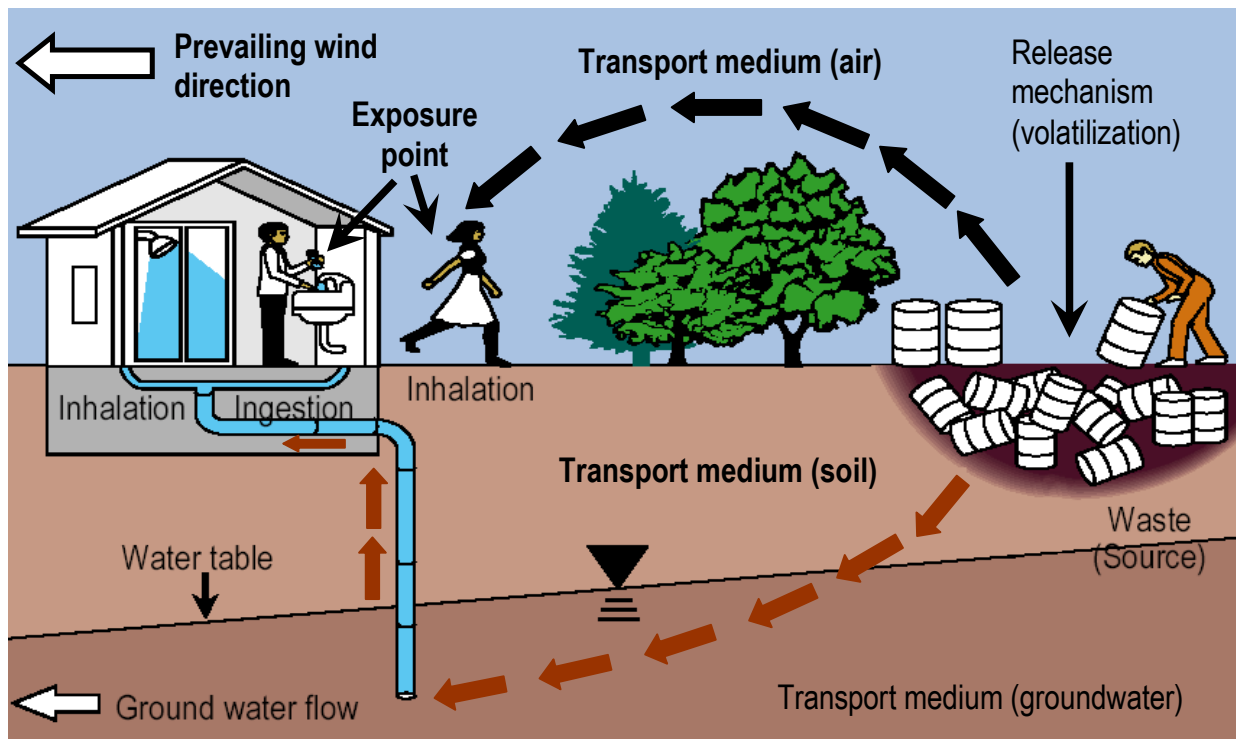
Figure 3.4
Environmental Assessment Conceptual Site Model (risk focus)

Qualitative evaluation of contaminant release, transportation and fate

This section addresses the following four factors:
- the source of the contaminants
- the nature of the contaminated media
- contaminant migration
- the geographical extent of current and possible future contamination

Identification of contaminants of concern

This section identifies the contaminants that pose a risk to human health. The factors to be considered include:
- concentration in media (air, soil, surface water, groundwater, sediments and biota)
- background level (nearby)
- bioavailability
- physical-chemical properties of the contaminants
- potential for bioaccumulation
- potency

Identification of exposure pathways

An exposure pathway is the link between the contaminant source and receptor. During the formulation of the problem, all the media (i.e., groundwater, soil, surface water, sediments, air and biota) should be considered. The means of exposure include:
- inhalation directly or after
- ingestion through drinking water or food, and
- dermal adsorption through skin.

It should be noted that these mechanisms can occur directly or after modification in the environment, e.g., biological uptake by plants, dissolution in water. Figure 3.5 illustrates the route of contaminant uptake by humans.

Figure 3.5
Routes of contamination uptake by Humans

Identification of receptors

Receptors can be identified from a review of the fate, transportation and potential release of contaminants. Receptors can be individual organisms, groups, or communities that are exposed to a contaminant.

Problem formulation checklist

Table 3.3 contains a typical checklist (Health Canada, 2004a) that can be used to identify land use receptors and exposure pathways for a given site.

Table 3.3
Problem Formulation Checklist

Land Uses (check [√] as appropriate)		Receptor Group(s) (check [√] as appropriate)		Critical Receptors (check [√] as appropriate)		Exposure Pathways (check [√] as appropriate)	
Agricultural		General public		Infant		Soil ingestion	
Residential/urban parkland		Employees		Toddler		Soil dermal absorption	
Commercial with daycare		Construction workers		Child		Particulate inhalation	
Commercial without daycare		Canadian Native communities		Teen		Vapour inhalation	
Industrial		Other (specify)		Adult		Groundwater ingestion	
Other (specify)				Other (specify)		Water dermal absorption	
						Produce ingestion	
						Fish ingestion	
						Wild game ingestion	
						Other (specify)	
						Other (specify)	
						Other (specify)	
						Other (specify)	

Toxicity Assessment

Toxicity assessment considers the adverse health effects associated with the chemical exposures, and the relationship between the magnitude of exposure and adverse effects. Toxicity assessment establishes either a dose-response relationship or a toxicological value for each contaminant of concern. Toxicity values for POPs can be obtained from published literature and/or government sources such as Health Canada (2004a,b), Environment Canada, and USEPA. For human health risk assessments, dose-response relationships are typically applied to carcinogens.

Equations for the derivation of health-based criteria

For carcinogens

$$Criterion\ (\mu g) = \frac{Upperbound\ Lifetime\ Excess\ Cancer\ Risk\ x\ Average\ Adult\ Weight\ x\ Conversion\ Factor}{Carcinogenic\ Slope\ Factor\ x\ Assumed\ Daily\ Water\ Consumption}$$

Source: NJDEP 2004

Where the default values are:
- *Average Adult Weight* $= 70\ kg$
- *Assumed Daily Water Consumption* $= 2\ litres\ per\ day$
- *Upper bound Lifetime Excess Cancer Risk* $= 1x10^{-6}$
- *Conversion Factor* $= 1,000\ \mu g/mg$
- *Carcinogenic Slope Factor* $= Value\ from\ Table\ 3.4$

Example Calculation – *Groundwater Quality Criterion for <u>DDT</u> Based on Human Health Concerns*

From Table 3.4, Carcinogenic slope Factor for DDT = 0.34 (mg/kg-day)[-1]

$$Criterion\ (\mu g) = \frac{1\ x\ 10^{-6}\ x\ 70\ x\ 1000}{0.34\ x\ 2} = 0.1$$

Table 3.4
Human Toxicity Reference Values (TRVs)

POP	Non-Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI /RfD (mg/kg-d)$^{-1}$	Source	Inhalation TC mg/m^3	Source	Oral SF (mg/kg-d)$^{-1}$	Source	Inhalation UR (mg/m^3)$^{-1}$	Source
Aldrin and Dieldrin	0.0001	HC 2004b			0.35	USEPA 2009		
Chlordane	0.0005	USEPA 2009	7x10^{-4}	USEPA 2009			0.1	USEPA 2009
Dichlorodiphenyltrichloroethane (DDT)	0.01	HC 2004b			0.34	USEPA	0.097	USEPA 2009
Endrin	0.0003	USEPA 2009						
Heptachlor	0.0004	USEPA 2009			4.5	USEPA 2009	1.3	USEPA 2009
Hexachlorobenzene	0.0008	USEPA 2009					0.46	USEPA 2009
Mirex	0.0002	USEPA 2009						
Toxaphene					1.1	USEPA 2009	0.32	USEPA 2009
Polychlorinated biphenyls (PCBs)	0.001	HC 2004b					0.1	USEPA 2009
Dioxins and Furans	2x10^{-9}	HC 2004b						

HC=Health Canada

For non-carcinogens and carcinogens with no slope factor available

$$Criterion\ (\mu g) = \frac{Reference\ Dose\ x\ Average\ Adult\ Weight\ x\ Conversion\ Factor\ x\ Relative\ Source\ Contribution}{Uncertainty\ Factor\ x\ Assumed\ Daily\ Water\ Consumption}$$

Source: NJDEP 2004

Where the default values are:

Average Adult Weight	*= 70 kg*
Assumed Daily Water Consumption	*= 2 litres per day*
Relative Source Contribution	*= 20%*
Conversion Factor	*= 1,000 µg/mg*
Reference Dose	*= Value from Table 3.4*
Uncertainty Factor	*= 10*

Example Calculation – Groundwater Quality Criterion for <u>Mirex</u> (a POP pesticide) Based on Human Health Concerns

From Table 3.4, Carcinogenic slope Factor for Mirex = 0.0002 (mg/kg-day)$^{-1}$

$$Criterion\ (\mu g) = \frac{2\ x\ 10^{-4}\ x\ 70\ x\ 1000\ x\ 0.2}{10\ x\ 2} = 0.14$$

Exposure Assessment

An exposure assessment examines a wide range of exposure parameters related to the "real world" in which the receptor is exposed to contaminants of concern. An exposure assessment is conducted to estimate:

- the magnitude of actual and/or potential human exposure
- the frequency and duration of these exposures
- the pathways by which humans are potentially exposed

Exposure assessment requires the establishment of a relationship between the contaminant concentration at the source and the exposure or intake at the receptor location, considering both the fate and transport of the contaminant and the behavioural characteristics of the receptor. It quantifies the magnitude and type of exposures of receptors to the contaminants.

Characterization of potential receptors

Each region may have its own receptor physical characteristics. If this information is not available, characteristics (required for exposure calculations) for a variety of common receptor groups can be found in the *USEPA Exposure Factors Manual* (USEPA, 1997b) and from Health Canada (2004a). Table 3.5 presents the specific values employed by Health Canada (2004a).

Table 3.5
Recommended Human Receptors and their Characteristics for Preliminary Quantitative Risk Assessments*

Canadian General Population						
Receptor Characteristic	Infant	Toddler	Child	Teen	Adult	Construction Worker
Age	0 - 6 mo	7 mo. – 4 yr	4 – 11 yr	12 – 19 yr	≥ 20 yr	≥ 20 yr
Body weight (kg)	8.2	16.5	32.9	59.7	70.7	70.7
Soil ingestion rate (g/d)	0.02	0.08	0.02	0.02	0.02	0.1
Inhalation rate (m^3/d)	2.1	9.3	14.5	15.8	15.8	15.8
Water ingestion rate (L/d)	0.3	0.6	0.8	1.0	1.5	1.5
Time spent outdoors (h/d)	--	--	--	1.5	1.5	8
Skin surface area (cm^2)						
Hands	320	430	590	800	890	890
Arms (upper and lower)	550	890	1480	2230	2500	2500
Leg (upper and lower)	910	1690	307	4970	5720	5720
Total	1780	3010	5140	8000	9110	9110
Soil loading to exposed skin (g/cm^2/event)						
Hands	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-3}$
Surfaces other than hands	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-4}$
Food ingestion (g/day)						
Root vegetables	83	105	161	227	188	NA
Other vegetables	72	67	98	120	137	
Fish	0	56	90	104	111	

*Source: Health Canada (2004a)

Exposure frequency and duration

While most assumptions about exposure frequency and duration are based on professional judgment. Table 3.6 provides some guidance.

Table 3.6

Exposure Duration and Frequency Assumptions for Preliminary Quantitative Risk Assessments*

	Agricultural Land	Residential Land	Commercial Land	Industrial Land	Construction Worker
Hours per day on site	24	24	8	8	8
Days per week on site	7	7	5	5	5
Weeks per year on site	52	52	52	48	2
Dermal exposure events per day	1	1	1	1	1
Meals of contaminated foods consumed per day	1	1	1	1	NA[1]
Life expectancy (years) for amortization of carcinogen exposures[2]	56/75	56/75	56/75	56/75	56/75

*Source: Health Canada (2004a)

[1] Not applicable

[2] If cancer risk is estimated for adults only, the 56-year duration of adulthood (20 to 75 years, inclusive) should be used; if cancer risks are estimated on the basis of lifetime average daily intake, then average life expectancy of 75 years should be used.

Exposure equations

In general, professional experience and judgment are required to develop exposure equations. Table 3.7 presents some equations, used by USEPA and Health Canada, for a limited number of exposure pathways.

Table 3.7
Recommended General Equation for Estimating Doses*

Inadvertent Ingestion of Contaminate Soil
The predicted intake of each contaminant via soil ingestion is calculated as

$$Dose\ (mg\ /\ kg\ /\ day) = \frac{CS\ x\ IR\ x\ CF\ x\ FI\ x\ EF\ x\ ED}{BW\ x\ AT}$$

where
CS = Concentration of Contaminant in Soil (mg/kg)
IR = Receptor Soil Ingestion Rate (mg/day)
CF = Conversion Factor (10^{-6} kg/mg)
FI = Fraction Ingested from Contaminated Source (unitless)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (year)
BW = Body Weight (kg)
AT = Averaging Time (period over which exposure is averaged – days)

Variable Values
CS :   Site-specific value
IR: 200mg/day (Children, 1 through 6 years old; USEPA, 1989b)
*   100mg/day (age groups greater than 6 years old; USEPA, 1989b)*
CF: 10^{-6} kg/mg
FI: Pathway-specific value
EF: 365days/year
ED: 70 years (lifetime; by convention)
*   30 years (national upper-bound time (90th percentile) at one residence; USEPA, 1989c)*
9 year (national medium time (50th percentile) at one residence; USEPA, 1989c)
BW: 70kg (adult, average USEPA, 1989c)
*   16kg (children 1 through 6 years old, 50th percentile; USEPA, 1985)*
AT: Pathway-specific period of exposure for non-carcinogenic effects
(i.e., ED x 365 days/year), and 70 years lifetime for carcinogenic effects
(i.e., 70 years x 365 days/year).

*Source:USEPA 1989a

Example Calculation – Ingestion of Mirex (POP Pesticide) Contaminated Drinking Water

The predicted adult intake of Mirex via ingestion of contaminated drinking water is calculated as

$$Dose\ (mg\ /\ kg\ /\ day) = \frac{CW\ x\ IR\ x\ EF\ x\ ED}{BW\ x\ AT}$$

where
CW = Concentration of Contaminant in Water (mg/kg) = 0.0005 (assumed laboratory test result found in unknown region)
IR = Receptor Water Ingestion Rate (litres/day) =2 litres/day
EF = Exposure Frequency (days/year) = 365 days/yr
ED = Exposure Duration (years) = 70 yrs (Adult life expectancy, according to USEPA is 70 years. This might vary from country to country.)
BW = Body Weight (kg)= 70 kg
AT = Averaging Time (period over which exposure is averaged – days) = 70 yrs x 365 days/year

$$Dose\ (mg\ /\ kg\ /\ day) = \frac{0.0005\ x\ 2\ x\ 365\ x\ 70}{70\ x\ 365\ x\ 70}$$
$$= 1.43x10^{-5}$$

Risk Characterization

Risk characterization, the final stage of the Site-Specific Risk Assessment process, is based on the projected intake of the contaminants of concern combined with established toxicity data to obtain a measure of risk. For non-carcinogens, human health risk is expressed in terms of hazard indexes. Risks for carcinogens are presented as a lifetime incremental cancer risk.

Non-carcinogens: Single–substance exposures

For substances presenting risks other than cancer, a Hazard Quotient (used by Health Canada) is used to evaluate the potential for non-carcinogenic effects. The rate of exposure to toxicity characterized by a Hazard Quotient is as follows:

$$Hazard\ Quotient = \frac{Estimated\ Exposure\ (\mu g\ /\ kg\ /\ day)}{Tolerable\ Daily\ Intake\ (\mu g\ /\ kg\ /\ day)}$$

The non-cancer hazard quotient assumes that there is a level of exposure (Reference Dose, Rfd, or Tolerable Daily Intake, TDI), below which it is unlikely for even sensitive people to experience adverse health effects. The greater the value of the Hazard Quotient above unity the greater the level of concern. Note that a ratio of 0.001 does not mean that there is a one-in-one-thousand chance of the effect occurring.

Carcinogens: Single–substance exposures

For substances deemed to be carcinogenic, an Incremental Life Cancer Risk (ILCR) is used to evaluate the potential risk for carcinogenic effects.

ILCR = Exposure (μg/kg/d) x Cancer Slope Factor (μg/kg/d)$^{-1}$

Cancer risk is often considered to be negligible if the estimated ILCR is ≤ 1 in 100,000, i.e., 10^{-5}. However, the USEPA employs 10^{-6} as its primary risk benchmark for "acceptable" exposure to carcinogens within the general population. Note that the recommended dermal absorption factor is summarized in Table 3.8.

Table 3.8
Prediction of intake dosage and recommended ingestion of contaminated drinking water*

Ingestion of Contaminated Drinking Water
The predicted intake of each contaminant via ingestion of contaminated drinking water is calculated as

$$Dose \ (mg/kg/day) = \frac{CW \ x \ IR \ x \ EF \ x \ ED}{BW \ x \ AT}$$

where
CW = Concentration of Contaminant in Water (mg/kg)
IR = Receptor Water Ingestion Rate (litres/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (year)
BW = Body Weight (kg)
AT = Averaging Time (period over which exposure is averaged – days)

Variable Values
CW: Site-specific value
IR: 2 litres/day (adult, 90th percentile; US EPA 1989c)
*   1.4 litres/day (adult, average; US EPA 1989c)*
*   Age-specific values US EPA 1989c*
EF: Pathway-specific value (for residents, usually daily –365 days/year)
ED: 70 years (lifetime; by convention)
*   30 year (national upper-bound time (90th percentile) at one residence; USEPA 1989c)*
9 year (national medium time (50th percentile) at one residence; USEPA 1989c)
BW: 70kg (adult, average USEPA 1989c)
*   Age-specific values (USEPA 1985, US EPA 1989c)*
AT: Pathway-specific period of exposure for non-carcinogenic effects
(i.e., ED x 365 days/year), and 70 years lifetime for carcinogenic effects
(i.e., 70 years x 365 days/year).

* Source: USEPA 1989a

Application of Site-Specific Risk Assessment to Contaminated Site Management

As mentioned previously in this module, sometimes technical, economic or environmental constraints preclude the remediation option. In these cases, a Site-Specific Risk Assessment can identify the contaminants, exposure pathways and receptors for a specific site. With this information, the owner/site operator must determine if the risks can be managed by exposure barriers and administrative controls instead of carrying out a complete remediation. Figure 3.3 illustrates the site-specific risk assessment process, which involves reducing, controlling, or preventing exposure to contamination. Site-specific risk management is a more flexible process for managing human health when complete remediation is not a viable option on a contaminated site. It should be noted, however, that the site is not considered completely remediated and requires long-term care and control by the responsible parties.

From a regulatory point of view (see Module 1: sections 1.2, 1.4 and 1.7) successful site–specific risk management is dependent upon the future diligence of the responsible parties in maintaining an acceptable management program and preventing any adverse effects. Unconditional closure will usually not be allowed if the site-specific conditions require ongoing exposure control to limit risk to a critical receptor.

MODULE 4

MANAGING CONTAMINATED SITES

This module guides you through the process of developing a strategy for contaminated site management. This process includes an examination of the risk management options.

The module describes various site remediation technologies, and presents a screening matrix system to help you select the appropriate technology for a specific site.

You will also find detailed worksheets that will help you classify and then prioritize sites for remediation according to risk.

4.1 INTRODUCTION

This module provides guidance on developing a strategy for contaminated site management. It also presents risk management options to assist users in selecting the best option for the specific site. The application of risk management for a POP-contaminated site is illustrated by a case study from Sudan. A screening matrix system is introduced as a tool to help readers select the appropriate technique for a specific site according to the local situation. The application of the screening system is illustrated by means of appropriate case studies. Theory and limitations of different remediation techniques are summarized. Means of proving that the POP-contaminated site has been properly managed or remediated and post-remediation monitoring procedures are also discussed.

The relationships of this module to the previous modules are that Modules 2 and 3 deal with one site at a time, whereas the first section of Module 4 assists in categorizing in the event that you need to manage a number of contaminated sites, with ordering according to a ranking of relative risk to set the priorities for remediation. Remediation and management are intended to comply with regulatory standards applicable to all contaminated media present at the site.

You will find in certain situations that the site requires short-term remedial measures because it presents immediate risks to human beings and the natural environment. For example, you may need to take immediate action to prevent the contaminant from continuous spilling or leaking.

Financial and economical components (Module 5) must be considered throughout the process of developing the strategies for managing POP-contaminated site plans.

4.2 STRATEGIES FOR MANAGING A POP-CONTAMINATED SITE

The successful management and remediation of a site contaminated by persistent organic pollutants (POPs) depends on the availability of sufficient site information to evaluate the required remedial measures. Obtaining sufficient data on a contaminated site's characteristics (see the discussion of detailed site investigations, DSIs, in Module 2) is a critical component to success. The ground may be complex depending on its geological formation, hydrological and soil conditions, as well as historical activities (see the discussion of preliminary site investigations, PSIs, in Module 2). Too little data will produce limited results, possibly requiring further site investigation (a revisit of the activities in Module 2) and additional future work to complete the task. Too much data may lead to excessive costs, which would likely curtail the site owner's willingness to remediate.

Detailed site investigation in developing countries is much more expensive than in developed countries. For example, for a typical ground situation in Nigeria and Ghana, one borehole drilling using a hollow auger over one to two days costs US$8,000 to US$12,000 (cost in 2010), whereas in Canada it only costs CAN $2,000 to $3,500 per day for three boreholes depending on the soil types and overburden situation. This difference in cost is mainly due to the high costs of equipment hauling (transportation) and rental, and of laboratory analysis. Analysis of one polychlorinated biphenyl (PCB) sample costs around US$140 in Nigeria. Each borehole might require the analysis of five to 10 samples at different depths; the number of samples per borehole depends on the complexity of the soil profile and the DSI sampling

strategy (see Module 2). A balance should therefore be maintained. Project cost, however, should be balanced with the environmental, social-political, and technical factors that are also at play.

The remediation of contaminated sites is an important part of site management, and the complicity of contaminants at a site determines the diversity of remediation technologies that can be used. There are comparatively numerous remediation technologies available with a host of emerging technologies currently being developed. The screening and selection of site remediation technology, which is the key to successful site restoration, is subject to many factors (politics, economics, technology, etc). Sites contaminated with POPs, due to the human health hazard and potential long-range transport issues, require urgent remediation and risk management, both in the developing and developed world.

This section outlines a step-by-step approach to developing strategies for POP-contaminated site management (as illustrated in Figure 4.1) when there is more than one contaminated site that needs to be managed. Once the processes described in Modules 2 and 3 have been completed for each site, the sequential steps in Figure 4.1 will help decision-makers prioritize the sites for remediation. This section will provide guidance on how to categorize/classify sites based on the extent of risk, and then rank them. Figure 4.2 illustrates the *Environmental site assessment* step from Figure 4.1 while Figure 4.3 focuses on the *Evaluation of results* step. The Site Classification Worksheet, and the accompanying User's Guide, in "Tools and Resources" (Section 4.9) are helpful tools for evaluating and prioritizing sites for remediation.

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┌─────────────────────────────────┐
│     Rationale for Remediation    │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│      Classification of Sites     │
└─────────────────────────────────┘
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┌─────────────────────────────────┐
│   Environmental Site Assessment  │
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│   Evaluation of Results with Respect to Goals │
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│ Development and Implementation of Remidial │
│              Action Plan                 │
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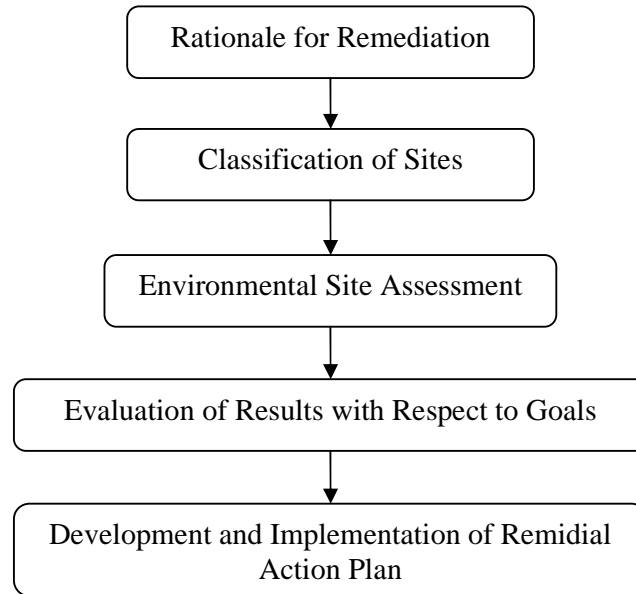
Figure 4.1
Remediation Plan for Persistent Organic Pollutants

The Rationale for Remediation

The reasons for remediation of a site must be justified. There are different factors that may lead to the requirement for remediation including the following:

- **Regulatory requirements:** Some remedial works are driven by regulatory requirements or, in severe cases, by court order. In such cases, remediation criteria are mainly governed by the regulatory agents.
- **Environmental responsibility:** Some actions are instigated in the interests of environmental responsibility. In these cases, remediation criteria are mainly defined by the site owner.
- **Commercial agreement:** Some actions may be conditions that are agreed when land is sold. In such cases, the remediation criteria are likely to be governed by mutual agreement between the parties involved.

In all cases, knowing the reasons for the remediation will lead to a more focused and efficient remediation approach that is more likely to succeed.

Site Categorization

Since many developing countries are faced with a large number of contaminated sites, it is important to promote consistency in site assessment and in the setting of management priorities. To this end, it is necessary to develop a categorization system that provides scientific and technical assistance in the identification of sites. The system should classify each contaminated site by risk type—high, medium or low—according to its current or potential adverse impact on human health and/or the environment. Once sites have been categorized, priorities for action can be assigned on a technical basis. When several sites are under consideration, the total scores (from the categorization system) for each site are ranked to determine the sites with the greatest urgency for early action, enabling resources to be directed to the areas of greatest concern.

It should be noted that the categorization system is not designed to provide a general or quantitative risk assessment, but is rather intended as a screening tool, specifically for the categorization and general prioritization of contaminated sites. The system screens sites with respect to the need for further action (e.g., characterization, risk assessment, remediation, etc.) to protect human health and the environment.

The User's Guide and Worksheets in Section 4.9 (*Tools and Resources*) presents one example of a categorization system that can be easily used in developing countries to assess the hazards of different sites. This Site Classification/Categorization System was developed by the Canadian Council of Ministers of the Environment (1992), and includes worksheets and a User's Guide. In this system, the three categories of site characteristics (the same three risk components discussed in Module 3, i.e., contaminant characteristics, exposure pathways, and receptors) are all weighted equally. A number of evaluation factors, each of which is assigned a score from 0 to 18 based on its importance, are then applied as assessment tools within each of the three categories.

Minimum data requirements

Before using the worksheets in Section 4.9 *Tools and Resources*, the following site information must be available:
- description of the site location
- type of contaminants or materials likely to be present at the site
- approximate size of site and quantity of contaminants
- approximate depth of water table
- geologic map or survey information (soil, overburden, and bedrock information)
- annual rainfall data
- surface cover information
- proximity to surface water
- topographic information
- flood potential of site
- proximity to drinking water supply
- users of adjacent water resources
- land use information

Although most of this information should have been collected during the preliminary site investigations (see Module 2), the reality for many developing countries is that data are not readily available or accessible due to the lack of resources and records. In these cases, it will be necessary to explore other options for obtaining background information such as, for example, interviewing local people who have been living in the area for a long time. This information can help to build capacity, such as developing a contaminated site database for the regulating agency (as described in the PSI in Module 2).

Environmental Site Assessment

The investigator should fully utilize the information obtained from contaminated site assessments (Module 3) identifiying the nature and extent of contamination (based on Module 2 DSI) and the impact and effects of contamination on human health and the environment as identified based on a risk assessment (Module 3). These assessment results from Module 3 for a POP-contaminated site should yield enough information to select effective remedial measures to mitigate or prevent negative consequences. In some cases, additional or a full site assessment may be needed, depending on the complexity of the POP-contaminated site, as discussed in Module 2.

Prior to embarking on the often long and expensive process of a full site assessment, it is advisable to obtain a preliminary overview of the significance of the environmental issues. Canada's National Guidelines for Decommissioning Industrial Sites (CCME, 1991) provide a model for a phased site assessment protocol, which is illustrated in Figure 4.2.

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┌─────────────────┐       ┌─────────────────┐
│ IDENTIFICATION  │       │ CLASSIFICATION  │
│       OF        │ ───►  │       OF        │
│  CONTAMINATED   │       │  CONTAMINATED   │
│      SITE       │       │      SITE       │
└─────────────────┘       └─────────────────┘
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Phase I — SITE INFORMATION ASSESSMENT

Phase II — RECONNAISSANCE TESTING PROGRAM

Phase III — DETAILED TESTING PROGRAM

Tier 1* CLEANUP CRITERIA DEVELOPMENT

Tier II* CLEANUP CRITERIA DEVELOPMENT (if necessary)

Phase IV DEVELOPMENT OF DECOMMISSIONING AND CLEANUP PLANS

Phase V IMPLEMENTATION OF SITE DECOMMISSIONING AND CLEANUP

Phase VI CONFIRMATORY SAMPLING AND COMPLETION REPORTING

SUPPLEMENTARY CONDITIONS * (if necessary)

———— Detailed Phased Approach
- - - - - - Optional Fast Track Approach

* Tier 1 cleanup criteria are based on existing numerical guidelines, and are not site-specific. Tier 2 cleanup criteria are generally applicable where Tier 1 guidelines are not promulgated or where background levels exceeding guidelines occur, and are developed using detailed assessment of site-specific factors. At some sites, supplementary conditions may complement cleanup criteria when available technology (or other factors) restricts the level of cleanup carried out, contaminants must be isolated on-site, or long-term remedial action is necessary.

Figure based on Figure 3 of National Guidelines for Decommissioning Industrial Sites (CCME, 1991)

Figure 4.2:
Phased Approach to Contaminated Site Management

One of the main reasons for the failure of remediation projects is inadequate site characterization and/or poor evaluation of the site characteristics, leading to the selection and implementation of ineffective remedial actions. (See Module 2 for detailed information on site characteristics.)

Evaluation of Results with Respect to Goals

When a POP-contaminated site has been identified and an initial characterization of the nature, extent and magnitude of contamination at the site has been completed, it must be determined whether the results exceed the generic guidelines. If contaminant concentrations at the site do not exceed established guidelines, no further action is required. If contaminant concentrations exceed the generic guidelines, however, it is necessary to develop an appropriate management strategy, i.e., a remediation strategy and/or a risk management strategy.

While a remediation strategy will establish the most appropriate cleanup objectives for a contaminated site, a risk management strategy will determine whether remedial action is required at all.

Risk management is the decision-making process in which an action is developed once a remediation level has been determined. It integrates a remediation strategy with technical, political, legal, social and economic considerations to develop risk reduction and prevention strategies. Generally, it involves one or more of the following:
- contaminant removal or reduction
- modifying or limiting use by receptor
- interception or removal of exposure

A remediation/risk management strategy is developed for a contaminated site to meet established remediation goals. Both strategies are intended to ensure that the remediation goals are attained more effectively, efficiently and economically.

In order to implement a remediation/risk management strategy, the following activities should be conducted before choosing appropriate technologies:
- evaluating applicable technologies
- conducting a cost-benefit analysis (see Module 5)
- preparing a remediation action plan
- selecting a contractor
- maintaining proper documentation, and communicating with stakeholders

The recommended steps for evaluating the results of the POP-contaminated site investigation and characterization (Modules 2 and 3) are illustrated in Figure 4.3.
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                ┌─────────────────────────────────────┐
                │  Contaminated Site Identification and │
                │           Characterization            │
                └─────────────────────────────────────┘
                                  │
                                  ▼
                ┌─────────────────────────────────────┐
                │ Develop Remediation / Risk Management │
                │              Strategy                 │
                └─────────────────────────────────────┘
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      ┌──────────────────────┐          ┌──────────────────────┐
      │  Remediation Strategy │          │   Risk Management     │
      └──────────────────────┘          └──────────────────────┘
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  ┌──────────────┐   ┌──────────────┐
  │ Criteria-Based│   │  Risk-Based   │
  │   Approach    │   │   Approach    │
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      ┌──────────────┐  ─ ─ ─ ─ ▶  ┌──────────────────────┐
      │ Recommended   │             │  Recommended Risk     │
      │ Remediation   │             │ Management Objectives │
      └──────────────┘             └──────────────────────┘
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                ┌─────────────────────────────────────┐
                │   Develop Risk Management Strategies  │
                └─────────────────────────────────────┘
                                  │
                                  ▼
                ┌─────────────────────────────────────┐
                │ Implement Remediation / Risk Management│
                │              Strategy                 │
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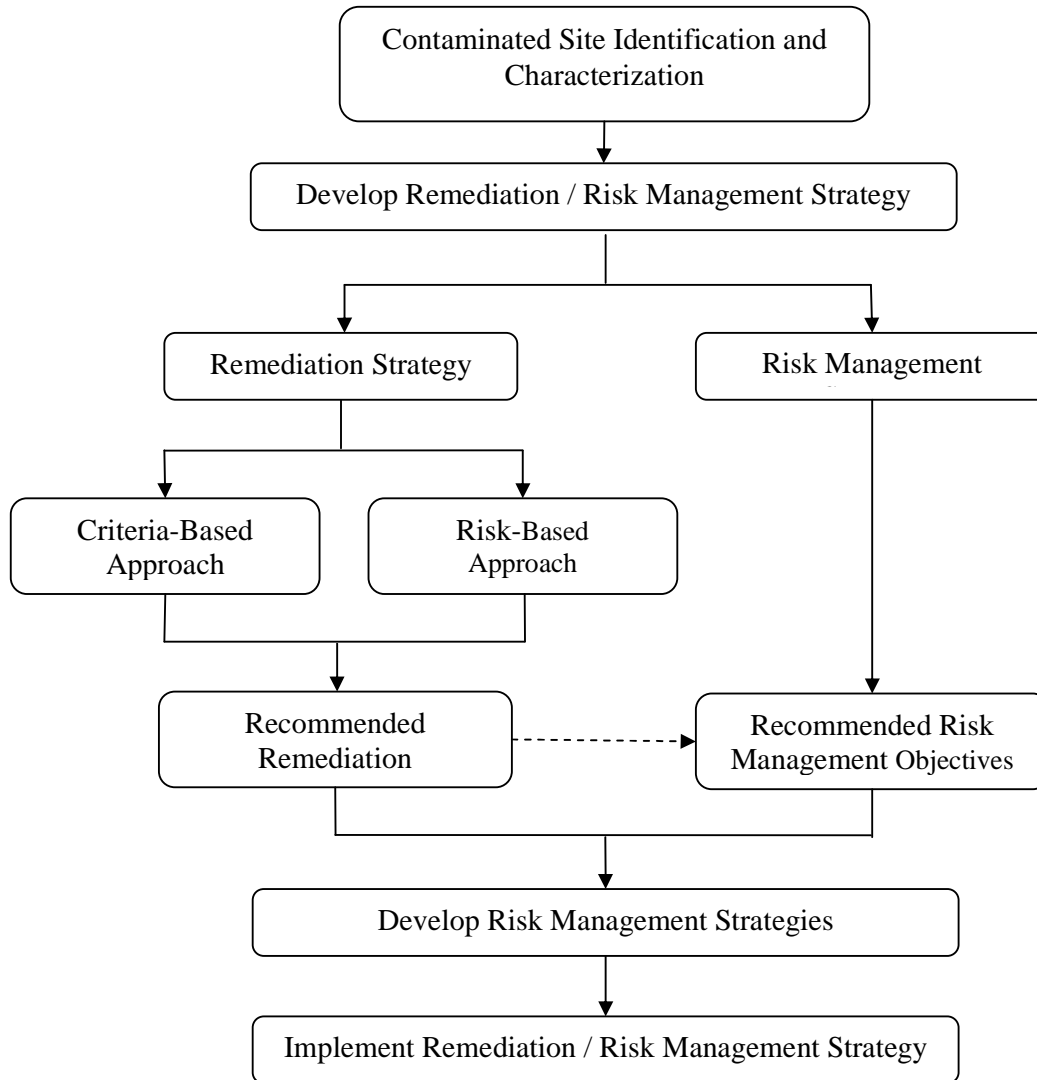
Figure 4.3:
Steps for Contaminated Site Assessment and Remediation

4.3   INTEGRATING RISK ASSESSMENT WITH CONTAMINATED SITE MANAGEMENT

The three preliminary site characteristics — contaminants, pathways, and receptors — are considered the three components of risk in risk assessment (as described in Module 3). All three components must be present for risk to occur. With a combination of these three components, we can develop a conceptual model that simulates a site's conditions and helps to assess potential areas of environmental concern. This allows the resources and subsequent effort to focus on the contaminants of concern as well as the receptors and pathways that are relevant to site remediation/risk management issues. The following basic questions must be answered when preparing the model:

- What are the contaminants on the site and what is their concentration?

- Is it possible for the contaminants to come into contact with site users? If so, how?
- Who are the site users?

Risk Management Options

Remediation through risk management deals with eliminating or controlling one or more of the three risk components: (i) contaminant, ii) exposure pathway, and iii) receptor. Figure 4.4 illustrates each risk component and its corresponding management options.

Removal of the contaminant component can be achieved by excavation or treatment of the contaminant, either on-site (in-situ) or off-site (ex-situ). Remediation can employ one method, or a combination of the available physical, chemical and biological methods. Remediation is considered as a proactive risk management solution that offers a permanent and certain end to managing risk in the environment. Alternative forms of risk management on a contaminated site, such as exposure barriers, administrative controls and/or partial remediation, may be acceptable to a regulatory agency in certain cases.

It should be noted that even if a source of contamination exists, there will be no risk to human health unless exposure is likely. Not all contaminants released to the environment reach points of contact with individuals by all pathways. For example, containment can retain chemicals within the contaminated site and prevent those chemicals from being transported to the receptor outside the site. Individuals using groundwater for drinking or other purposes would not be exposed to those contaminants via this pathway. In this case, the groundwater exposure pathway is termed "incomplete" and the risk assessor would conclude that it does not contribute to increased health risks. "Complete" pathways, those by which contaminants have reached or are likely to reach points of contact with individuals, are therefore analyzed in depth in a risk assessment; however, future land use options may be limited in these situations.

Sometimes, it is not possible to remove the contaminants or exposure routes due to technical or economic or environmental constraints, the last resort is to control the receptor's accessibility by relocations and imposing land use restrictions. Risk management options are discussed further in the next section.
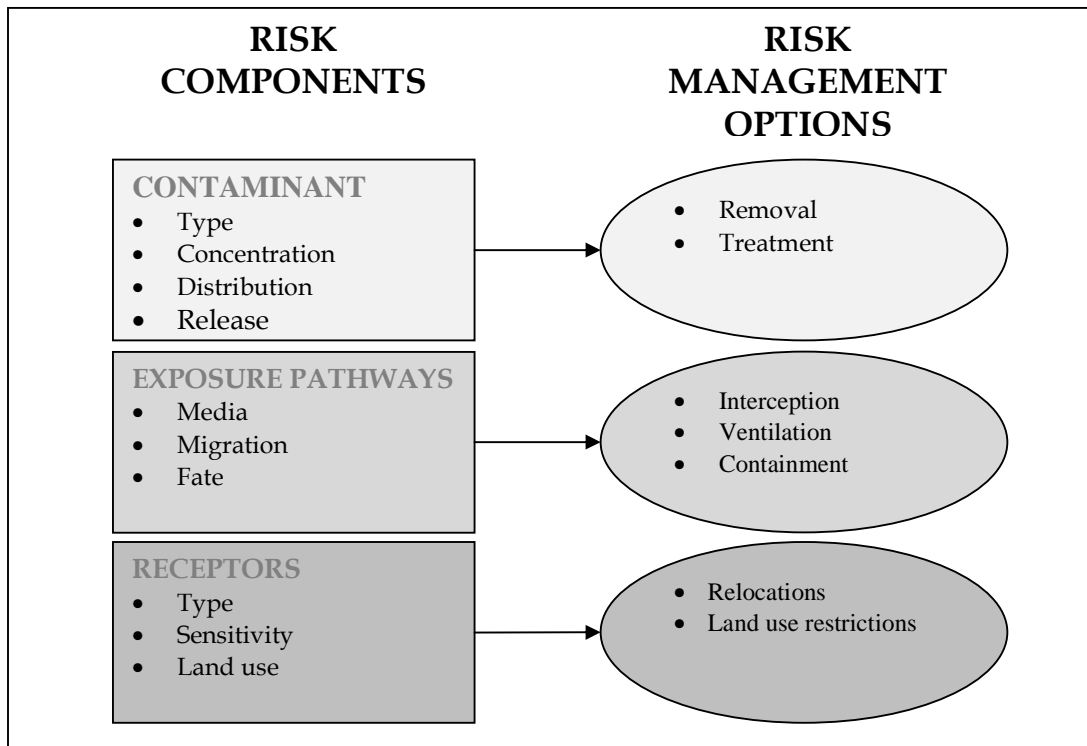
Figure 4.4
Risk components and their corresponding management options

4.4 MANAGEMENT / REMEDIATION of POP-CONTAMINATED SITES

The remediation and/or management of a contaminated site, must comply with any regulatory standards that apply to all contaminated media present at the site. Remediation usually requires a great deal of time in both the planning and implementation stages. In certain situations, however, a site may require short-term remedial measures because there are immediate risks to human beings and natural environments. For example, if the POP storage tanks are leaking or spilling, short-term measures must be taken to prevent further expansion of the contaminated zone. These measures include:

- source control
- site stabilization-immobilization of contaminants, including installing a barrier
- temporarily moving people

In other situations, intermediate measures may need to be established to guide the remediation activity when complete removal of a contaminant source is not feasible in one aggressive remedial effort and contaminants remaining in the sites still exceed the regulatory standards. Intermediate measures (ASCE, 2007) include:

- depletion of contaminant source adequately to allow for natural attenuation
- reduction of dissolved phase contaminant concentration outside a source zone
- decrease in mass discharge rate or flux from a contaminant source
- reduction of the mass or volume of a contaminant source
- prevention of migration of remediation fluids beyond a treatment zone

Long-term remediation strategies are intended to implement a comprehensive monitoring program that properly characterizes the baseline (pre-remediation) condition and monitors improvements to be achieved through targeted remediation. Long-term remedial measures focus on compliance with all regulatory standards applicable to all contaminated media (e.g., groundwater, soil, and soil vapour) present at the site.

Case Study: Management of Hasahisa Pesticides Dump, Gezira Scheme[1], Sudan (1993 – 95)

The information of this case study was provided Dr. Eisa M. Abdellatif, President of the Sudanese Environment Conservation Society from 1992 to 1997 and currently Chief Technical Advisor, Zayed International Prize for the Environment, United Arab Emirates. Analysis of the extent of DDT contamination was carried out by Mr. Mohamed Elqadi as part of his Master thesis project in 1992 under the supervision of Dr. Abdellatif, who was an associate Professor of Ecology at the Institute of Environmental Studies in University of Khartoum. Post-management site monitoring results were not available. During a site visit to the same area after 16 years by Dr. Abdellatif, photographs were taken to reflect the present situation at the Hashisha pesticides dump.

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[1] Scheme is a state or province.

Historical synopsis of pesticides in Gezira

Pesticides were first introduced in Gezira in 1945. Figure S1 shows the location of the Gezira scheme (Sudan-Africa) in the shaded area just south-east of Khartoum. The major pesticides were DDT, Aldrin and Dieldrin. Organo-Phosphorous compounds (Dimethoates) were introduced during the 1960/61 season, Carbamates (Sevin) in 1970/71 and Pyrethroids in 1980/81.

Figure S1
Geographical location of (Sudan-Africa); area of interest here, Gezira Agricultural Scheme, is the shaded area below Khartoum.

Even though DDT and Dieldrin were banned for Agricultural use for the 1981/82 season, DDT continued to be applied to control insects, i.e. for human and animal health purposes, and it was also used in sugarcane plantations. Aldrin and Dieldrin continued to be used for cotton seed dressing (Aldrex T & Dieldrex B), and for rat and locust control.

Pesticides were widely used in other areas in Sudan, such as in the New Halfa Scheme, Elsuki, Nuba Mountains and Sugar Cane plantations areas to combat termite infestation.

The agrochemicals were imported via Port Sudan and transported, mainly by railway, to the main storage location in Gezira Scheme for distribution to other smaller storage locations in the scheme, which covered a total area of 8,800 km^2 with a network of irrigation canals extended 4,300 km long. The storage areas were often poorly ventilated without concrete floors.

Obsolete pesticides were often kept in the open sites in drums or bags, which did not meet basic safety standards. Corroded/leaked drums and torn bags were often found in those stores.

Approximate tonnage and distributions of obsolete pesticides in Gezira Scheme (1980s-1990s)

There were ~913 tons of POPs in 156 storage sites. The quantity of contaminated soil was estimated to be 2650 tons, and it is estimated that there were a further 312 metric tons of containers. The Gezira Scheme was considered to be the worst agricultural area in Sudan in terms of the quantities of obsolete POPs, POP-contaminated soil and POPs-contaminated containers. Not surprisingly, most of these storage sites were located near irrigation canals and villages. Many obsolete pesticide containers were also scattered in villages, some of them even dating back to the 1950s and 1960s.

Hasahisa - main storage area of agrochemcials

The main storage area for agrochemicals in the Gezira Scheme is located on the outskirts of a small town called "Hasahisa". Agrochemicals were distributed from this storage area via railway to other storage locations. Therefore, large quantities of chemicals were found at this storage location at all times, including newly arrived and obsolete pesticides. Old drums and bags were leaking, and there was an odour of obsolete pesticides in the surrounding areas.

A small community of 25 railway worker families was located near the storage area. These people suffered the consequences of the improper storage of obsolete pesticides. In 1987 and in response to complaints from the community, the Crop Protection Department of the Gezira Scheme decided to burry obsolete pesticides inside the storage yard. They dug two pits with a total area of ~100m² and dumped large, but unknown, quantities of liquid and solid chemicals (mainly DDT) into these two pits, then covered them with wastes and soils. After this action, the soils in this area changed colour with time and also became oily.

There are two major seasons in the Gezira scheme which cause significant distribution and migration of pesticides to the surrounding community – the dry season and the wet season. During the dry season, contaminated dust and soil particles were blown into the surrounding areas, causing irritation to eyes, noses and respiratory systems. During the rainy season, surface runoff carried the pesticides-contaminated soil and dissolved chemicals in temporary pools. Children played in this water, and domestic animals drank this water. (See attached picture of the colourful water, Figure S2).

Figure S2
Fenced pesticides store at Qurashi Station and the colored polluted water

In 1992, the serious health impact in this area became apparent. The children in the area and in surrounding areas were in poor health, suffering from headaches, nausea, and allergic symptoms such as running eyes and noses. The rate of miscarriages was extremely high at 80% rate of miscarriages, with 21 miscarriages in 25 families.

DDT was determined to be >1000 ppm in top soil. DDT was also found in mother's milk and human blood. Fortunately, the major soil series comprising the Gezira scheme are Hosh, Suleimi, and Laota. These soils contain more than 40% of fine clay, which is predominantly smectite (a mixture of montmorillonite and beidellite)[2]. These soils have very low permeability, so that the DDT was held in the top soil, and the groundwater was not contaminated.

With the support of the Federal Minister of Agriculture, the Sudan Development association, the Sudanese Environment Conservation Society and the Federal National Council (Parliament), after their investigation by the Technical Committee, ordered the site to be remediated.

Site remediation and management

The Technical Committee decided that the best available and most affordable method to manage the problem was to remove the pesticides-contaminated soils and place them in a containment system. Waste containment is one of the methods shown in Figure 4.4. The purpose is to eliminate the pathway of contact with the receptors after applying risk assessment to manage a contaminated site. The management technique relies on surface and subsurface engineered barriers to contain the toxic waste to prevent the flow of contaminants offsite, and/or to render waste less harmful to humans and ecosystems for many years. Normally, locally available clay minerals such as montmorillite / smectite can be applied as the barrier material.

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[2] Adam, Anderson and Dixon (1983) in Soil Sci Soc Am J. 47:1233-1240.

Concrete barriers with of dimensions 20 m × 10 m × 5 m in depth were constructed within the storage perimeters (see Figure S3). Approximately 80 barrels of 55-gallon-drums of mainly DDT and pesticide-contaminated soil were placed in this concrete containment system. The smectite local soil acted as a bottom barrier to prevent migration of DDT. In addition, an outer fence with a 250 mm high concrete bench was constructed around the storage perimeter to stop surface runoff from the site. The sheds were reconstructed with concrete floors and channels, which led to concrete pits for evaporation in case of leakage of some drums stored in the sheds. The cost of the whole process of remediation alone was ~US$117,000 (in 1993), not including the cost of investigations and prior study.

Figure S3
The pesticides grave under concrete

The 25 cm short barrier and the fence built all around the perimeter of the storage area to contain runoffs

Figure S4
The fence around the perimeter of the storage, it also prevents children from entering and playing in the storage area

Figures S5 to S9 show the post-remediation situation after 16 years. These photos were taken in October 2009. Based on the interviews by Dr. Abdellatif, the health of the community improved significantly. It is concluded that the containment system was effective in eliminating the contamination pathway.

Figure S5
One of the sheds has collapsed

Figure S6
One of the sheds has been cleaned

Figure S7
Obsolete pesticides in corroded containers under the collapsed sheds

Figure S8
Containment system: the contained dump is still in good condition. Water has no colouring

Figure S9
The nearby community

Best Available Techniques and Best Environmental Practice

In developing countries, economic viability is a critical factor when dealing with contaminated sites. Best available techniques (BAT) and best environmental practice (BEP) for developing countries correspond to those remediation techniques/technologies developed on scale that allow implementation in any site, locally or off site, under economically and technically viable conditions, taking into consideration the costs and advantages. The critical factors in designating BAT techniques for developing countries are:

- environmental sustainability
- technical viability
- economic viability (see Module 5)
- resource availability

The next section features a proposed screening matrix system (Li, 2008) that takes these critical factors into consideration when selecting BAT/BEP techniques for developing countries. This matrix, as shown in Table 4.2, is a valuable tool for site owners, as well as for government agents who are responsible for determining suitable technologies for managing POP-contaminated sites.

Superfund program has provided us the frequency of methodology application of site remediation. Number of projects completed in the United States of America by technology in superfund sites (1982 - 2002) is shown in Figure 4.5.
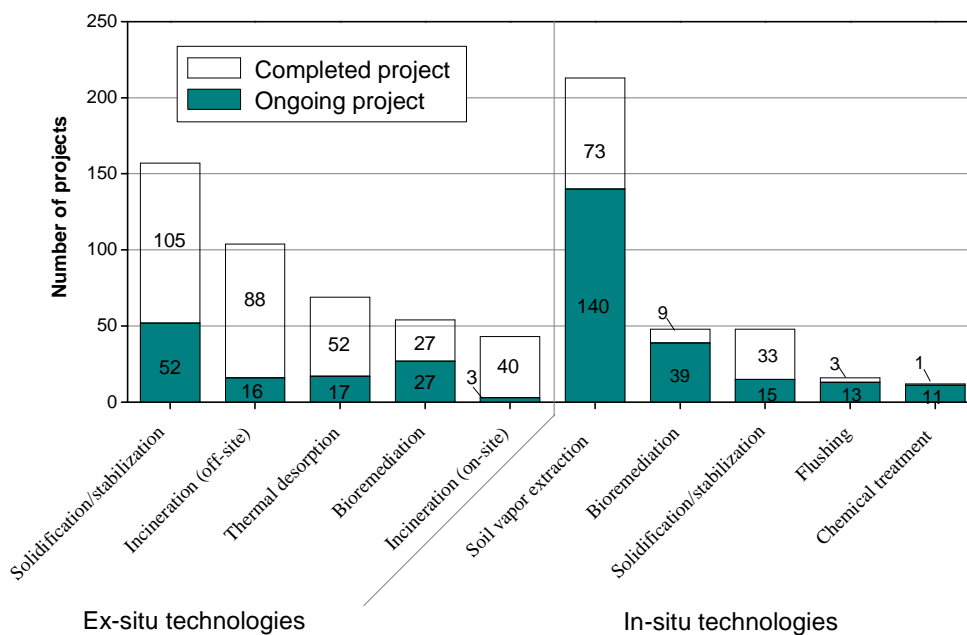
Figure 4.5
Superfund remedial actions: number of projects completed by technology (1982 - 2002)

How to Use the Treatment Technologies Screening Matrix

Treatment technologies screening matrices are common tools for screening potentially applicable commercialized technologies for POP remediation projects. A matrix allows the user to screen in-situ (with a few exceptions) technologies to treat POPs and POP-contaminated sites for countries at various stages of development.[3]

The grading system for the screening matrix is outlined in Table 4.1. The screening matrix presented in Table 4.2 (Li, 2008) provides a foundation for decision-making and for choosing an appropriate technology for specific sites in developing countries. The matrix, which is based on three sets of criteria, can be readily expanded as more commercial technologies become available.

Logistics

The criteria for comparison are based on on-site technology (in-situ/ex-situ), except for landfilling and incineration. The matrix is based on three different sets of criteria, to encourage a wide-ranging evaluation of the technologies: (a) technical considerations, (b) health and environmental considerations, and (c) economic considerations. Although equal weight is applied to each criterion, weighting factors can be established to reflect the differing relative importance of different criteria in each jurisdiction; however, each factor should at least be considered in all cases in order to evaluate comprehensively various technological options. It is important to remember that evaluations will be based on available information, some of which may not be complete or fully accurate. The weighting factors given in Table 4.2 are based on North American situations. Some criteria listed below are not included in Table 4.2 because of their high variability (e.g. geographic locations, chemicals used, etc.). They are therefore difficult to quantify. Generalized values are given as examples, but they could be insignificant. More information is provided in the next sections regarding the grading system.

Technical considerations
Site-specific requirements:
- soil temperature dependence
- soil moisture dependence
- particle size/distribution of soil
- permeability/clay content
- organic matter (this requirement is not included in the matrix due to insufficient data and information)
- space available
- proximity of population or sensitive sites

Resource Requirements:
- pre-treatment
- power/energy/fuel
- water quantity, quality and seasonal variations
- chemicals

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[3] The U.S Federal Remediation Technologies Roundtable has developed a similar screening matrix for remediation technologies.

- equipment
- monitoring
- skilled labour
- transportation: roads, rail, canals, etc.
- off-gas treatment
- post-treatment
- excavation

Health and Environmental Considerations

These considerations include the impact on the local, regional and global environment in all aspects, i.e., air, water, soil and sediments:

- hazardous by-product(s)
- worker health and safety
- odours, aesthetic factors

Financial considerations

- pre-treatment cost
- labour cost
- monitoring cost
- power/fuel cost
- equipment cost
- installation/decommissioning cost
- operating and maintenance cost
- disposal cost
- transportation cost
- water cost
- patent cost
- post-treatment cost
- influence on regional economy

Grading System for the Screening Matrix

Table 4.1 provideds an explanation of the simple grading system used in the matrix. In this matrix evaluation, the lower the score, the better the technology for a specific site. Each criterion can be weighted by multiplying by a "weighting factor", accounting for the relative importance of different attributes. The sum of all scores, multiplied by the corresponding weighting factors, results in a total qualification grade, which allows a comparison of alternatives and the selection of the best technology for the specific site, subject to its own local and specific conditions. The weighting factor for each item can be adjusted upward or downward as circumstances change, depending on local factors.

Table 4.1
Grading System for Screening Matrix

Rating Code	Explanation
1 - No/Low	Low degree of intensity or not required: in cost, negative impact or skilled labour
2 - Average	Average degree of intensity: in cost, negative impact or skilled labour
3 - Yes/high	High degree of intensity or requirement: in cost, negative impact or skilled labour

There is no *a priori* methodology for assigning specific weighting factors to the criteria listed in Table 4.2. Individual site owners must assign an appropriate weighting factor for each criterion based on local priorities and regulatory requirements. For example, the cost of water and energy can vary radically between different communities; as a result, their weighting factors are likely to differ. And regulatory requirements for developing countries can also be very different from those of developed countries; thus the corresponding weighting factors with respect to environmental impacts are likely to differ as well.

Please note that additional factors, such as greenhouse gas generation and climate change effect, can also be included in Table 4.2, and the weighting factors could range from one to 10 instead of one to three. The sensitivity of the matrix could increase, and, in doing so, may better reflect the significant controlling factors in the selection of the remediation techniques.

Table 4.2
Proposed screening matrix system for choosing an appropriate technology for a specific site in a developing country.

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCR[ii]	Solvent Extraction	Vitrification	Pyrolysis	MCD[i]	Sanitary landfilling
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On site	On Site	On Site	On Site	Off Site
Efficiency	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99%	99.99%	70-91%	N/A
Estimated cost (US$/m^3) *	$140-360	N/A	$350-450/$350-700	$122-154* partial cost	$147-626	$55-360	$500-630	$125-400	$500-8,000	$375-500	N/A	$150
Technical Consideration												
Site-Specific Requirement												
Soil Temperature Dependence	1	1	2	2	2	3	3	1	3	3	3	1
Soil Moisture Dependence	3	3	3	3	3	3	3	3	3	3	3	1
Particle Size	2	2	3	3	2	3	2	2	1	1	3	1
Permeability/clay content	1	1	1	1	1	3	1	3	1	1	1	1
Space Requirement	2	1	2	2	1	3	2	3	1	1	1	1
Resource Requirement												
Pre-treatment	2	2	2	3	1	1	3	2	1	1	1	1
Power	3	1	3	1	1	1	3	3	3	3	2	1
Water	1	1	1	3	2	3	1	2	1	1	1	1
Chemical/enzyme	1	1	1	3	1	3	3	3	1	1	1	1
Monitoring	3	1	3	3	1	1	3	3	2	3	2	1
Skilled Labour	3	1	3	3	1	2	3	3	3	3	2	1
Transportation	1	3	1	1	1	1	1	1	1	1	1	3
Off-Gas Treatment	2	1	3	3	1	1	3	1	3	2	1	1
Post-treatment	1	1	1	3	1	1	1	3	1	1	1	1
Excavation	3	3	3	3	1	1	3	3	3	3	2	3
Subtotal	29	23	32	37	20	30	35	36	28	28	25	19

[i] MCD = Mechanochemical dehalogenation
[ii] GPCR = Gas Phase Chemical Reduction
N/A=Not available due to high variability

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Table 4.2 (continued)

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCRii	Solvent Extraction	Vitrification	Pyrolysis	MCDi	Sanitary landfilling
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On site	On Site	On Site	On Site	Off Site
Efficiency	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99%	99.99%	70-91%	N/A
Estimate cost (US$/m³) *	$140-$360	N/A	$350-$450/ $350-$700	$122-$154* partial cost	$147-$626	$55-$360	$500-$630	$125-$400	$500-$8,000	$375-500	N/A	$150
Health & Environmental Consideration												
Impact on Environment	2	2	1	1	1	1	1	1	2	2	1	2
Bi-products												
Hazardous	3	3	1	1	1	1	3	1	3	2	1	2
Subtotal	5	5	2	2	2	2	4	2	5	4	2	4
Financial Consideration												
Pre-treatment Cost	1	1	3	3	1	1	3	2	1	1	2	1
Labour cost	2	2	2	3	3	2	2	3	3	2	2	1
Monitoring Cost	3	1	3	3	2	2	3	3	2	2	2	1
Power/fuel Cost	3	1	3	2	1	1	3	1	3	3	2	1
Equipment Cost	3	2	3	3	1	1	3	2	3	2	2	1
Installation/Decommissioning Cost	2	1	3	3	1	1	3	2	3	3	2	1
Operating & Maintenance Cost	2	1	3	3	2	2	3	2	3	3	2	1
Chemical (or equivalent) Cost	1	1	1	3	1	2	3	3	1	1	1	1
Disposal Cost	1	3	1	1	1	1	1	1	1	1	1	3
Transportation Cost	1	3	1	1	1	1	1	1	1	2	1	3
Water Cost	1	1	1	3	2	3	1	1	1	1	1	1
Patent Cost	1	1	3	3	1	1	3	1	3	2	2	1
Post-Treatment Cost	1	1	1	3	1	1	3	3	1	2	1	1
Sub-total	21	18	25	31	17	18	29	23	25	24	19	16

Rating Code :　　1 - No/Low　　2 - Average　　3 -Yes/High　　　　　　　　　　N/A = Not Available

Source: Li (2008)

4.5 CASE STUDIES: APPLYING THE SCREENING MATRIX TO POP-CONTAMINATED SITES IN CHINA

The case studies in this section illustrate how the screening matrix can be applied to select remediation technologies for three representative POP-contaminated sites in China:
   1. Abandoned site of a chlorine and alkali plant
   2. Abandoned site of a dye plant with chlorobenzene
   3. PCB-polluted site

Case Study #1: Abandoned Site of a Chlorine and Alkali Plant

Brief introduction of the site

This former chlorine and alkali plant was established in 1938 in a suburban area in southwest China. Over the past 50 years, however, the region has been gradually surrounded by the urban area and is now an industry-concentrated area. Residential, business and cultural facilities are also close to the site. Figure 4.6 shows the location of the contaminated site and the land use plan.

The former plant has a total area of 312,987 m^2. The western section contains the old plant is covered by crushed building waste. The eastern part includes the new plant covered by waste from demolished buildings. In front of the former chemical plant there are two piles of polluted soil more than five metres high. The northeast corner of the site is an industrial waste stack area of 6,000 m^2 with chloride waste. The chimney on the east side of the site is still not demolished.

The main products produced in the western section were inorganic chemical products such as caustic soda, hydrochloric acid, liquefied chlorine gas, bleaching liquor and ferric trichloride. In the eastern section, the main products were methane chloride, sorbierite, freon, benzene, and so on. In 2004 a major chlorine tank explosion in the chemical plant caused casualties and damages to the plant, and production activities were stopped at the end of that year. The site buildings were demolished and removed except for the office buildings in the western section. The site demolition stopped in 2007, but many residents continued to dig for iron products and other recyclable objects. After production had stopped, the site's surface was basically covered by the wastes of demolished buildings.

This site has been planned as residential and commercial land use in the future design of the city with luxury residential buildings, business centres, leisure and sightseeing district, parks and public activity centres.

Figure 4.6
Location of the contaminated site and the land use plan

Environmental and hydrogeological conditions

According to local statistics, the geology of the site area belongs to the East Sichuan fold belt. The terrain goes down from north to south. The soil profile, from top to bottom, comprises cultivation soil, clay, sandy clay and base rock, mostly cretaceous sandstone and clay shale. The soil layer is one to three meters, and the yellow- and purple-brown clay is partly porous. Little groundwater was detected in this area. This area has a mild climate with abundant rainfall (the main source of the groundwater), long periods of no-frost and low-speed winds. The meteorological conditions are not favourable for the dispersal of harmful substances.

Main pollutants

The main pollutants are listed in Table 4.3. According to the sample analysis, the pollutants of relatively high density are mainly organic chlorine compounds.

According to the sample analysis, pollutants of relatively high density comprise mainly organic chlorine compounds, including PCA pentachloroethane, HCBD, HCB, PeCB, dioxin, HCH, PCE, carbon tetrachloride and chloroform. A health risk assessment was conducted for the main pollutants using a risk-based corrective action (RBCA) model, which involves soil sampling and identification of high-risk areas for POP contamination (see Figure 4.7). The results showed that the area was seriously polluted by industrial wastes in the stack and silt areas, where the levels of hexachlorethane, HCB, pentalin, hexachlorobutadiene and tetracarp greatly exceed the restoration guideline value (with 10^{-4} as the risk level). The highest HCB content was 6,254 times higher than the soil quality standard for commercial land use established by the Ministry of Environmental Protection, People's Republic of China. Carbon trichloride and hexachlorobutadiene were also 9,330 and 291 times higher than the maximum levels in the above-mentioned standard.

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Table 4.3
Contaminants in the soil samples

Contaminant		Concentration (mg/kg)
Heavy metals	Arsenic (As)	1.1-6.9
	Barium (Ba)	45-4,665
	Cadmium (Cd)	0-0.9
	Chromium (Cr)	25.0-49.5
	Lead (Pb)	5.0-149.6
	Mercury (Hg)	0-0.8
POPs	Hexachlorobenzene (HCB)	0-12,510
	Dioxin	0-0.017
Semi-volatile and volatile organic compounds	Carbon Tetrachloride	0-2,702
	Tetrachloroethylene (PCE)	0-1,940
	Pentachloroethane	0-1,480
	Pentachlorobenzene (PeCB)	0-1,360
	Hexachlorobutadiene (HCBD)	0-6,120
	Hexachloroethane (PCA)	0-933,170
	Hexachlorocyclohexane (HCH)	0-1,539
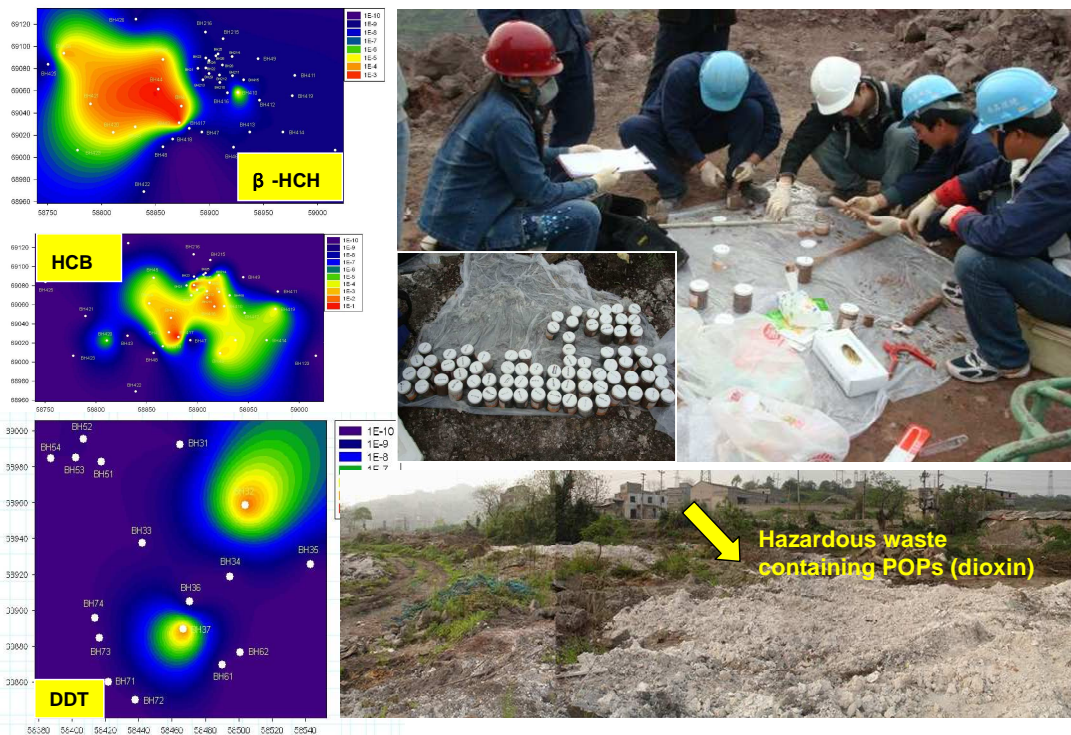
Figure 4.7
Soil sampling and identified high risk area of POP-contaminated soils based on health risk assessment (RBCA Model)

Groundwater testing and analysis from the monitoring well revealed that the carcinogenic risks of most pollutants were less than 10^{-6}, but the risk value of dioxin in some locations exceeded 10^{-4}. Although the risk levels of carbon trichloride, hexachlorobutadiene, carbon

tetrachloride, chlorylene, tetracarp, trichloroethane, chloroform, gammexane and other pollutants in soils exceeded 10^{-4}, the hazard quotient was above 1, indicating that these pollutants are likely to cause risks to human health. The groundwater in the western section was not polluted.

Using the screening matrix to select the treatment technologies

Some contaminants such as pentachloroethane, HCD and HCB were determined in soils with high concentrations, and almost pure substances of hazardous chemicals were present in some locations simultaneously with hexachloroethane. This kind of POP-contaminated soil should be treated separately according to China's national guidelines for hazardous waste (HW45/261-085-45).

When the screening matrix (introduced in the last section) was applied, incineration, phytoremediation and sanitary landfilling were selected as the three preferential methods (see Table 4.4).

Phytoremediation was excluded because it is an extremely time-consuming process and not suited to this site given the properties of the contaminants involved. And although sanitary landfilling presented good potential because of its low cost, environmental safety and efficient timeline, it was also excluded because there was no complementary landfill system near the contaminated site, especially for POPs.

Incineration was selected as the most appropriate technology. The score for incineration was the lowest with respect to decreasing the health and environmental impacts, and to financial support. A new and environmentally friendly incineration production line in a cement plant, specially developed for the treatment of contaminated soils, was already located near the contaminated site. The factors of lower labour and transportation costs in this region were also taken into account. Using the incineration method meant that this site could be redeveloped as a residential area within a year.

Table 4.4
Case Study #1: Matrix system for selecting treatment technologies

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCR	Solvent Extraction	Vitrification	Pyrolysis	MCD	Sanitary landfilling
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On site	On Site	On Site	On Site	Off Site
Efficient	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99	99.99	70-91%	
Estimate cost (US$/m³) *	140-360	N/A	350-450/350-700	122-154* partial	147-626	55-360	500-630	125-400	500-8,000	375-500	N/A	150
Technical Consideration												
Site Specific Requirement												
Soil Temperature Dependence	1	1	2	2	2	3	3	1	3	3	3	1
Soil Moisture Dependence	3	3	3	3	3	3	3	3	3	3	3	1
Particle Size	2	2	3	3	2	3	2	2	1	1	3	1
Permeability/clay content	1	1	1	2	2	3	2	3	2	1	1	2
Space Requirement	2	1	2	1	2	2	2	3	1	1	1	3
Resource Requirement												
Pre-treatment	2	2	2	3	1	1	3	2	1	1	1	1
Power	3	2	3	1	1	1	3	2	3	3	2	1
Water	1	1	1	3	2	2	1	2	1	1	1	1
Chemical/enzyme	1	1	1	3	1	2	3	3	1	1	1	1
Monitoring	3	1	3	3	1	1	3	3	2	3	2	2
Skill Labour	2	1	2	3	2	2	3	3	3	3	1	1
Transportation	1	2	1	1	1	1	1	1	1	1	1	3
Off Gas Treatment	2	1	3	3	1	1	3	1	3	2	1	1
Post-treatment	1	1	1	3	2	1	1	3	1	1	1	1
Excavation	2	3	3	3	1	1	3	3	2	3	1	1
Sub-total	27	23	31	37	24	27	36	35	28	28	23	21

Table 4.4 (continued)

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCR	Solvent Extraction	Vitrification	Pyrolysis	MCD	Sanitary landfilling
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On site	On Site	On Site	On Site	Off Site
Efficient	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99	99.99	70-91%	
Estimate cost (US$/m³) *	140-360	N/A	350-450/350-700	122-154* partial	147-626	55-360	500-630	125-400	500-8,000	375-500	N/A	150
Health & Environmental Consideration												
Impact to Environment	2	2	2	1	1	1	1	1	2	2	1	2
Bi-products												
Hazardous	3	2	2	2	1	1	3	3	3	3	1	3
Sub-total	5	4	4	3	2	2	4	4	5	5	2	5
Financial Consideration												
Pre-treatment Cost	1	1	3	3	1	1	3	2	1	1	2	2
Labour cost	1	1	1	2	2	1	1	1	2	2	1	1
Monitoring Cost	2	1	2	3	2	2	3	3	2	2	2	1
Power/fuel Cost	3	1	2	2	1	1	3	1	3	3	2	1
Equipment Cost	3	1	3	3	1	1	3	2	3	2	2	1
Installation/Decommissioning Cost	2	1	2	3	1	1	3	2	3	3	2	1
Operational & Maintenance Cost	2	2	2	3	2	2	3	2	3	3	2	1
Chemical (or equivalent) Cost	1	1	1	3	1	2	3	3	1	1	1	1
Disposal Cost	1	2	1	1	1	1	1	1	1	1	1	3
Transportation Cost	1	3	1	1	1	1	1	1	1	2	1	3
Water Cost	1	1	1	3	2	2	1	1	1	1	1	1
Patent Cost	2	1	3	3	1	2	3	2	3	2	2	1
Post-treatment Cost	1	1	1	3	2	1	3	3	1	2	1	2
Sub-total	21	17	23	33	18	18	31	24	25	25	20	19
Total	**53**	**44**	**57**	**73**	**44**	**47**	**71**	**63**	**58**	**58**	**55**	**45**

Case Study #2: Abandoned Site of a Dye Plant Containing Chlorobenzene Compounds

Brief introduction of the site

The predecessors of the dye plant, which was founded in 1956, were several enterprises that developed from small workshops that traded in wholesale and retail of imported fuels; later these enterprises mainly manufactured various dyes. This plant stopped all its production and moved to another site in June 2003. The soil in the plant site is all alkali, with pH values ranging from 7.4 to 9.5. The site covers an area of 400,000 m^2 (see Figure 4.8), including (1) production workshops for dyes such as phthalocyanine copper, turquoise blue, indigotin, new indigotin, phthalocyanine blue, etc; (2) living quarters of the former plant; (3) former office quarters, including offices and a research unit; (4) workshops; and (5) storage rooms.
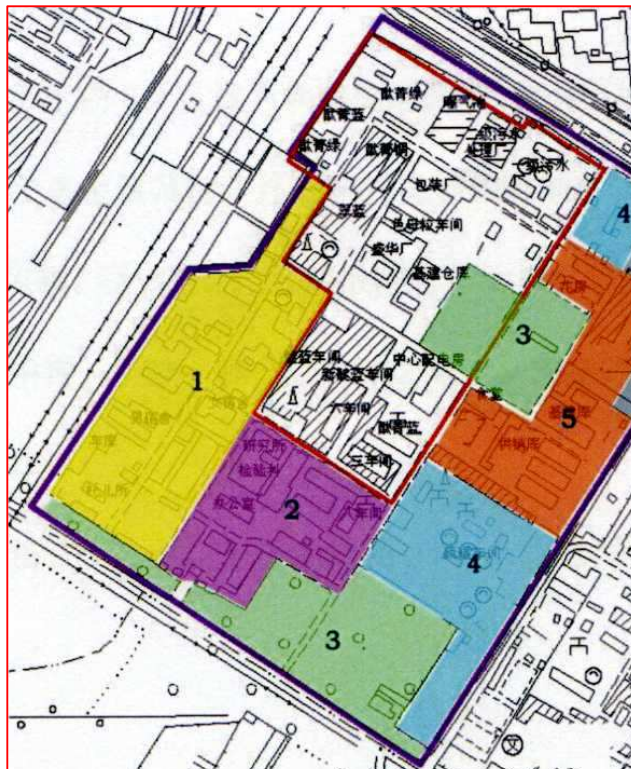
Figure 4.8
Location of the contaminated site

Environmental and hydrogeological conditions

The dye plant lies at the middle and lower parts of an alluvial-pluvial area. The confined aquifer is composed of fine and silty sand, and contains little gravel. The quaternary pore water system comprises the phreatic water, micro-artesian water (20-40 m), shallow confined water (40-80 m), and the middle and deep confined water (less than 150 m).

Main pollutants

The dye plants produced disperse dye, vat dye and organic pigments, which were mainly dyes and pigments of the phthalocyanine series. The main pollutants include PCBs, heavy metals (cadmium and arsenium), 1,2,4-trichlorobenzene and HCB. The POPs mainly exist at the site of the former dye workshops.

Selection of treatment technologies using the screening matrix

The screening matrix developed for this site took into consideration both the requirements of the various technologies and the level of economic development in Beijing.

Based on the score of the screening matrix (Table 4.5), the following remedial technologies were the potential remedial technologies for this site: incineration, thermal desorption, phytoremediation, bioremediation, MCD, and sanitary landfilling. However, MCD was excluded because reliable operating parameters were not available. Incineration was ruled out because of the lack of adequate space on the site and the long-distance transportation required for off-site incineration. Phytoremediation, bioremediation and sanitary landfilling were also excluded because of time issues, because the biodegradation of chlorobenzene compounds is difficult, and because these compounds are volatile. After eliminating these other options, thermal desorption was selected as the most appropriate treatment for this site.

Table 4.5

Case Study #2: Matrix system for selecting treatment technologies

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCR	Solvent Extraction	Vitrification	Pyrolysis	MCD	Sanitary landfilling
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On site	On Site	On Site	On Site	Off Site
Efficient	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99	99.99	70-91%	
Estimate cost (US$/m³) *	140-360	N/A	350-450/ 350-700	122-154* partial cost	147-626	55-360	500-630	125-400	500-8,000	375-500	N/A	150
Technical Consideration												
Site Specific Requirement												
Soil Temperature Dependence	1	1	2	2	2	3	3	1	3	3	3	1
Soil Moisture Dependence	3	3	3	3	3	3	3	3	3	3	3	1
Particle Size	2	2	3	3	2	2	2	2	1	1	3	1
Permeability/clay content	1	1	1	1	1	3	1	3	1	1	1	1
Space Requirement	2	1	1	2	1	1	2	3	1	1	1	1
Resource Requirement												
Pre-treatment	2	2	1	3	1	1	3	2	1	1	1	1
Power	3	2	1	1	1	1	3	3	3	3	2	2
Water	1	1	1	3	2	2	1	2	1	1	1	1
Chemical/enzyme	1	1	1	3	1	2	3	3	1	1	1	1
Monitoring	3	1	1	3	1	1	3	3	2	3	2	1
Skill Labour	3	1	1	3	1	2	3	3	3	3	2	1
Transportation	1	2	1	1	1	1	1	1	1	1	1	3
Off Gas Treatment	2	1	3	3	1	1	3	1	3	2	1	1
Post-treatment	1	1	1	3	1	1	1	3	1	1	1	1
Excavation	3	3	2	2	1	1	3	3	3	3	2	3
Sub-total	29	23	22	36	20	25	35	36	28	28	25	20

Table 4.5 (continued)

	Combustion			Non Combustion								Sanitary landfilling
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCR	Solvent Extraction	Vitrification	Pyrolysis	MCD	
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On site	On Site	On Site	On Site	Off Site
Efficient	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99	99.99	70-91%	
Estimate cost (US$/m³) *	140-360	N/A	350-450/350-700	122-154* partial	147-626	55-360	500-630	125-400	500-8,000	375-500	N/A	150
Health & Environmental Consideration												
Impact to Environment	2	2	1	1	1	1	1	1	2	2	1	2
Bi-products												
Hazardous	3	3	1	1	1	1	3	1	3	2	1	2
Sub total	5	5	2	2	2	2	4	2	5	4	2	4
Financial Consideration												
Pre-treatment Cost	1	1	3	2	1	1	3	2	2	1	2	1
Labour cost	2	2	2	2	2	2	2	2	2	2	1	2
Monitoring Cost	3	1	1	3	2	2	3	3	2	2	2	1
Power/fuel Cost	3	1	2	2	1	1	2	1	2	2	2	1
Equipment Cost	3	1	3	3	1	1	3	2	3	2	2	1
Installation/Decommissioning Cost	2	1	2	3	1	1	3	2	3	3	2	3
Operational & Maintenance Cost	2	2	2	3	2	2	3	2	3	3	2	1
Chemical (or equivalent) Cost	1	1	1	3	1	2	3	3	1	1	1	1
Disposal Cost	1	2	1	1	1	1	1	1	1	1	1	2
Transportation Cost	1	3	1	1	1	1	1	1	1	2	1	3
Water Cost	1	1	1	2	2	3	1	1	1	1	1	1
Patent Cost	1	1	1	2	1	1	3	1	2	2	2	1
Post-treatment Cost	1	1	1	3	1	1	2	3	1	2	1	1
Sub-total	22	18	21	30	17	19	30	24	24	24	20	19
Total	**46**	**46**	**45**	**68**	**39**	**46**	**69**	**62**	**57**	**56**	**47**	**43**

Case Study #3 - Site Polluted by PCBs

Brief introduction of the site

This case study focuses on the Zhejiang Province site chosen as the "China PCBs Management and Disposal Demonstration Project" by China and the World Bank, supported by the global environment fund (GEF). This demonstration project is a response to the Stockholm Convention requirements that the environmentally harmless disposal of equipment containing or polluted by PCB liquids must be finished by 2028. It will help China find out more about PCB pollutants, promote the progress of the covenant and enhance the management and disposal of PCBs.

Historically, this site was used for burying dismantled power capacitors until it was purchased by a local real estate developer in September 2007. The elevated concentration of PCBs in the soil of this site was only determined after excavating the capacitor-containing PCBs residues. (Figure 4.9).
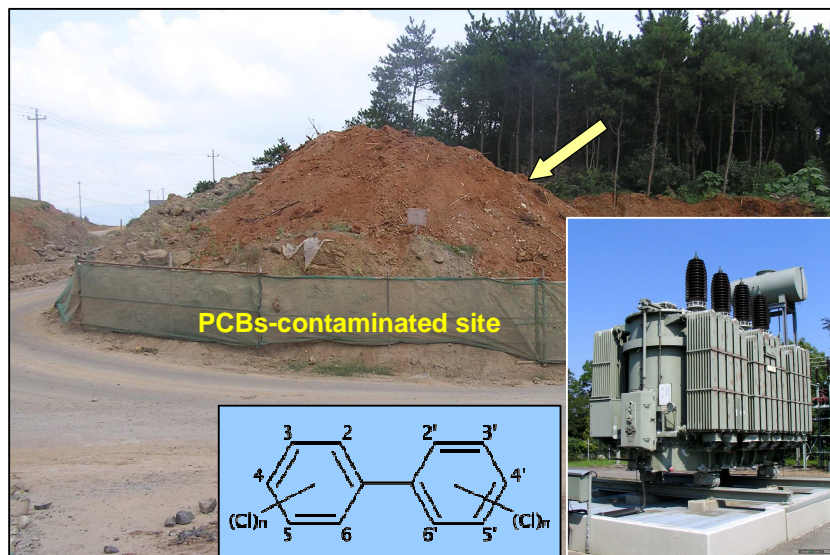

Figure 4.9
Location of PCB-contaminated site

Environmental and hydrogeological conditions

Around the area where the capacitors were placed, simple means have been used to surround and isolate the earth hummock where the capacitors are enclosed. The earth hummock is about 25 m from east to west, 16 m wide from north to south, and 5 m high. The top of the hummock is partly covered with new soil, which is about 2.4 to 3.0 m deep. Both sides of the hummock are construction roads, 3.0 m and 4.5 m wide. Near the hummock, there is a faint odour from the waste oil of the capacitors. Because the enclosed area sits on top of the relatively high Tashan Mountain, the groundwater will not affect construction there.

Main pollutants

Since different pollutant wastes require different clearing processes, it is necessary to classify the pollutants at the enclosed site; calculate the amounts of various wastes according to the classification results; and determine the packing methods, packing containers, number of containers and transport means. In light of the existing state of the PCBs wastes, the PCBs wastes can be classified as follows:

- PCB-contaminated soil
- capacitors and damaged components of capacitors
- pollutant wastes produced in the operation process, including:
  - materials (cleaning rags, wood chips, etc) containing adsorbed PCBs
  - personal protective devices (protective clothes, gloves, one-off protective clothes, etc)
  - packaging (packing container, impervious membrane and impervious bags)
- the PCB washing and rainwater collected in the areas

Selection of treatment technologies using the screening matrix

The potential technologies identified in the screening matrix included thermal desorption, phytoremediation and bioremediation (see Table 4.6). Since the biodegradation of PCBs is difficult, the remediation of a PCB-contaminated site by the phytoremediation and bioremediation methods would require considerable time. Although thermal desorption is a slightly more expensive than phytoremediation and bioremediation, it is a relatively effective for treatment of PCB-contaminated soil and would take less time than the other two methods. Thermal desorption was therefore selected as the final treatment technology, and it was applied in the actual treatment of PCB wastes in Shenyang city.

Table 4.6
Case Study #3: Matrix system for selecting treatment technologies

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCR	Solvent Extraction	Vitrification	Pyrolysis	MCD	Sanitary landfilling
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On Site	On Site	On Site	On Site	Off Site
Efficient	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99	99.99	70-91%	
Estimate cost (US$/m³) *	140-360	N/A	350-450/ 350-700	122-154* partial cost	147-626	55-360	500-630	125-400	500-8,000	375-500	N/A	150
Technical Consideration												
Site Specific Requirement												
Soil Temperature Dependence	1	1	2	3	2	3	3	2	3	3	3	1
Soil Moisture Dependence	3	3	3	3	3	3	3	3	3	3	3	1
Particle Size	2	2	3	3	2	3	2	2	1	1	3	2
Permeability/clay content	1	1	1	2	2	3	1	3	1	1	1	2
Space Requirement	3	1	2	2	2	2	2	3	1	1	1	1
Resource Requirement												
Pre-treatment	2	2	2	3	1	2	3	2	1	1	1	1
Power	3	3	2	1	1	1	3	3	3	3	2	1
Water	1	1	1	3	2	2	1	2	1	1	1	1
Chemical/enzyme	1	1	1	3	1	2	3	3	1	1	1	1
Monitoring	3	2	2	3	1	1	3	3	2	3	2	3
Skill Labour	3	2	2	3	1	2	3	3	3	3	2	2
Transportation	1	3	1	2	1	1	1	1	1	1	2	3
Off Gas Treatment	2	2	2	3	1	1	3	1	3	2	1	2
Post-treatment	1	1	1	3	2	1	1	3	1	1	1	1
Excavation	3	3	2	3	1	1	3	3	3	3	2	3
Sub-total	30	28	27	39	23	28	35	36	28	28	26	25

Table 4.6 (continued)

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytoremediation	Bioremediation	GPCR	Solvent Extraction	Vitrification	Pyrolysis	MCD	Sanitary landfilling
In/Ex situ	Ex	Ex	Ex/In	Ex	In	In/Ex	Ex	Ex	In/Ex	Ex	Ex	Ex
On Site/Off site	On site	Off site	On Site	On Site	On Site	On Site	On Site	On site	On Site	On Site	On Site	Off Site
Efficient	99.99%	99.99%	93-99.8%	99.99%	N/A	60-80%	99.99%	95-99%	99.99	99.99	70-91%	
Estimate cost (US$/m^3) *	140-360	N/A	350-450/ 350-700	122-154* partial	147-626	55-360	500-630	125-400	500-8,000	375-500	N/A	150
Health & Environmental Consideration												
Impact to Environment	3	3	1	1	1	1	2	2	2	2	1	3
Bi-products												
Hazardous	3	2	1	2	1	1	3	2	3	2	1	3
Sub-total	6	5	2	3	2	2	5	4	5	4	2	6
Financial Consideration												
Pre-treatment Cost	1	1	3	3	1	1	3	2	1	1	2	1
Labour cost	2	2	2	3	3	2	2	2	3	2	1	2
Monitoring Cost	3	2	2	3	2	2	3	3	2	2	2	2
Power/fuel Cost	3	3	2	2	1	1	3	1	3	3	3	1
Equipment Cost	3	2	2	3	1	1	3	2	3	2	2	1
Installation/Decommissioning Cost	3	1	2	3	1	1	3	2	3	3	2	1
Operational & Maintenance Cost	2	2	2	3	2	2	3	2	3	3	3	1
Chemical (or equivalent) Cost	1	1	1	3	1	2	3	3	1	1	1	1
Disposal Cost	1	2	1	1	1	1	1	1	1	1	2	3
Transportation Cost	1	3	1	1	1	1	1	1	1	2	1	3
Water Cost	1	1	1	3	2	3	1	1	1	1	1	1
Patent Cost	3	1	2	3	1	1	3	1	3	2	2	1
Post-treatment Cost	1	1	1	3	1	1	3	3	1	2	2	3
Sub-total	25	22	22	34	18	19	32	24	25	25	24	21
Total	**61**	**55**	**51**	**76**	**43**	**49**	**72**	**64**	**58**	**57**	**52**	**52**

Lessons Learned from Applying the Screening Matrix

The exercise of applying the screening matrix to three case studies in China has revealed both the strengths of the matrix in its current form along with potential areas for refinement.

1) The results from the application of the screening matrix to the three case studies are basically consistent with the remediation technologies actually adopted at these sites. This shows that it is practicable to use the matrix method to screen remediation technologies for POP-contaminated sites, resulting in a much quicker and labour-saving decision-making process. See Table 4.7 for a summary of the priority treatment technologies selected for the three case sites according to the screening matrix.
2) The recommended technologies for the above three sites were incineration and thermal desorption. Note that the optimum remediation technologies may vary significantly for different sites and locations.
3) It may be advisable to add further factors to the matrix. For example, remediation time can be an important factor in developing countries because most sites that require urgent remediation are located in valuable redevelopment land in city centres. In addition, future usage of land is another factor that should be included in the matrix as this can restrict the choice of remediation technology.
4) The matrix could be further refined by setting a weight value for each factor that corresponds to the reality of the specific situation. The matrix currently assigns equal weight to each factor. For example, when considering technology, the maturity of the technology is of great significance and should have a relatively high weight value.
5) Although the matrix currently includes a wide range of remediation technologies, it does not include all technologies available; thus it could benefit from expanding the list of technologies. In addition, the 11 technologies that are featured could be further classified into subclasses. For example, the cement kiln, is only one of the available incineration technologies.

Table 4.7
Preferred Technologies Selected by the Screening Matrix

	Case #1			Case #2			Case #3		
Selected Technologies	Incineration	Phyto-Remediation	Sanitary landfilling	Phyto-remediation	Sanitary landfilling	Thermal Desorption	Phyto-remediation	Bio-remediation	Thermal Desorption
Technical Consideration	23	24	21	20	20	22	23	28	27
Health & Environmental Consideration	4	2	5	2	4	2	2	2	2
Financial Consideration	17	18	19	17	19	21	18	19	22
Total Score	**44**	**44**	**45**	**39**	**43**	**45**	**43**	**49**	**51**

4.6 AN OVERVIEW OF SITE REMEDIATION TECHNOLOGIES

This section provides an overview of established, demonstrated and emerging remediation technologies for POP-contaminated sites listed in Table 4.2 of Section 4.3. It covers the technologies, together with their site requirements, costs, advantages and limitations[1]. For consistency, the order of discussion follows the same order as listed in Table 4.2 of Section 4.3, with combustion technologies treated first, followed by non-combustion technologies.

Among the technologies reviewed here, incineration, bioremediation (Bioremediation (DARAMEND® & Xenorem™), solvent extraction, vitrification (PACT, PLASCON™ and GeoMelt™), gas phase chemical reduction, pyrolysis (STARTECH), and ball milling/mechano-chemical dehalogenation (MCD™) are established technologies. Thermal desorption and super critical extraction (SCE) have at least been demonstrated. Phytoremediation is an emerging technology. Many of these POP remediation technologies are proprietary and protected by patents, as a result, they could be expensive to adopt and might not be affordable in developing countries. However, because of the competition between technologies for existing market and differences in local conditions, there may well be potential for improving proprietary techniques, or for adaptations that would make them more suitable to local situations in developing countries. In past decades, incineration, thermal desorption and bioremediation have been the principal techniques used (See Figure 4.5 of Section 4.3).

Incineration

Overview

Incineration treats POPs in solids and liquids by subjecting them to temperatures typically greater than $500^{\circ}C$ in the presence of oxygen. These conditions cause volatilization, combustion, and destruction of the organic compounds. The technology can be scaled down, with trailer-mounted versions of conventional rotary kiln and fluidized bed incinerators in existence. At large sites where the cleanup will require several years, it may be feasible to construct an incinerator onsite. Economic reasons are often the key factor in determining whether mobile, transportable, fixed, or offsite commercial incineration will be provided at a given site. The applicability of incineration to the remediation of POP-contaminated soil or sediment may be limited by the types and concentrations of metals present in the waste. When soil or sediment containing metals is incinerated, some metals vaporize, reacting to form other metal species, while less volatile metals remain with the soil residuals. Metals in ash, scrubber sludge, or stack emissions, if improperly managed, can result in potential exposures and adverse health effects.

Site requirements

The site should be accessible by truck or rail, and a graded or gravel area is required for setup of onsite mobile systems. For a typical commercial-scale unit, two to five acres are required for the overall system site including ancillary support. A stack of height exceeding that of local buildings and trees should be available or provided as part of the project. Standard high-voltage, three-phase electrical service is generally needed. A continuous water supply

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[1] This section is mainly extracted from Li (2008) Remediation Treatment Technologies: Reference Guide for Developing Countries Facing Persistent Organic Pollutants. For details, please refer to this document.

must be available at the site. Various ancillary equipments may be also required along with process-generated waste treatment equipment. Special handling measures should be provided to hold any process residual streams until they have been tested to determine their acceptability for disposal or release. Depending on the site and the nature of the waste, a method to store waste that has been prepared for treatment may also be necessary. Storage capacity depends on waste volume and equipment feed rates.

Cost

The cost of incineration includes the relatively fixed costs of site preparation, permitting, and mobilization/demobilization; and variable operational costs, such as labour, utilities, and auxiliary fuel. Average costs of the treatment system are said to range from \$140 to \$360/m^3 (1989 US dollars) (USEPA 1997).

Advantages and limitations

A well-designed incinerator will have the following advantages:
- capability of the highest overall degree of destruction and control for the broadest range of hazardous waste streams
- Can achieve stringent cleanup levels
- broad application capability

The limitations of this treatment technology are as follows:
- The inorganic components of hazardous wastes are not destroyed by the process.
- Continuous perfectly stable operation of a man-made facility operated by humans with heterogeneous or variable feed streams is unattainable.
- Performance can be limited by the physical properties and chemical content of the waste stream.

Thermal Desorption (TD)

Overview

Thermal desorption is primarily an ex-situ treatment technology that uses direct or indirect heat. Most thermal treatment technologies involve a two-step process. In step 1, heat is applied to a contaminated soil or sediment to vaporize the contaminants into a gas stream. In step 2, the gas stream from step 1 is collected, condensed or destroyed. Several gas treatment technologies may be used to meet regulatory requirements prior to discharge.

Thermal desorption is capable of treating various materials, including soil, sediment and sludge, contaminated with a wide range of organic contaminants. SVOCs (semi-volatile organic compounds), pesticides, and other compounds with boiling points up to about 300°C are typically processed through direct- or indirect-contact thermal desorption units. Contaminants with boiling points above 300°C, such as PCBs, dioxins, and furans, may be treatable with higher-temperature systems. It is cost effective to implement thermal desorption on wastes containing up to 10 per cent organics and a minimum of 20 per cent solids (USEPA 1991).

Site requirements

The system requires at least a 50 m by 50 m space for installation. Components such as the desorber, particulate control and gas treatment units are usually transported on modified flat-bed semi-trailers.

Cost

Costs for onsite thermal treatment vary widely depending on conditions specific to the site. Unit costs at some recent cleanups have ranged from US$350/m^3 to $450/m^3 for ex-situ systems and from US$350/m^3 to $700/m^3 for in-situ systems (1990 dollar value) (USEPA 1991; Depercin 1995).

Advantages and limitations

TD has the following advantages:
- The organic contaminants are separated from the medium to an off-gas stream where the vapours are treated directly or condensed before treatment.
- TD has the added advantage of separating SVOCs.
- The total volume of material requiring subsequent treatment is typically small in comparison to the volume of the contaminated medium at any given site.
- (TD may be viewed as a step in a sequence of remediation steps.
- Groups of organic contaminants can be selectively removed from the medium by careful control of the treatment temperature.

Its imitations include the following:
- Most TD systems require excavation and transport of the contaminated medium.
- The contaminated medium must contain at least 20 per cent solids to facilitate placement of the waste material into the desorption equipment.
- Materials handling of soils that are tightly aggregated or largely clay can result in poor processing performance due to caking.
- Very high moisture content may result in low contaminant volatilization.
- Since TD does not destroy contaminants, subsequent treatment of residuals is required.
- TD units have the potential to produce PCDDs/PCDFs when treating chlorinated compounds.

Supercritical Extraction (SCE)

Overview

SCE is based on the supercritical fluid (SCF) extraction of organic compounds from different solid matrices for analytical purposes. Early efforts focused on extracting harmful organic chemical from spiked soils/sediments using supercritical carbon dioxide (SCCD) were followed by later tests on contaminated soils and sediments from different sites. SCE has been under study in pilot-scale studies, but it has apparently not yet been commercialized. The SCF is chosen such that it has a higher affinity for contaminants than for the bulk material of the solid matrix.

Most SCE processes use SCCD individually or mixed with co-solvents. SCE uses the SCF properties to extract contaminants at optimum temperature, pressure, and flow rate conditions. Rather than destroying in-situ pollutants at relatively low concentrations with significant energy and/or for materials to be absorbed by the bulk matrix, the SCE process is the first step of a two-step or multi-step remedial technology. SCE does not destroy either contaminants or the soil/sediment. Instead, the extracted pollutants are highly concentrated and subsequently destroyed more cost effectively. All SCE processes for remediation purposes employ similar unit operations including feed preparation, extraction, separation of solids and solvent, and recovery of the solvent.

Cost

Equipment and excavation contribute to the main cost of the treatment technology, which is reported to range between US $122/m^3 and $154/m^3. (Montero et al., 1996).

Advantages and limitations

This technique has several benefits:
- There is high extraction efficiency (up to 99.99 per cent).
- The cleaning process can be completed in a few minutes.
- There is no second-hand pollution.
- The soil structure is left intact.

However, there are also several limitations:
- SCE is not a stand-alone technology.
- It is machine-intensive, requiring further treatment method of the extracts.
- The high pressures require special pressure vessels and other components.
- Soil excavation is required, increasing the risk of atmospheric contamination.
- Very specific equipment is needed, limiting the applicability to developing countries.

Phytoremediation

Overview

Phytoremediation uses vegetation, enzymes derived from the vegetation, and other complex processes, to isolate, destroy, transport, and remove organic pollutants from contaminated soils. Phytoremediation has been applied at several sites on the US National Priorities List, as well as other hazardous waste sites, to help meet regulatory requirements. The diversity of pollutants to which it can be applied—crude oil, metals, explosives, pesticides, chlorinated solvents and numerous other contaminants—is the prime reason for the technology's rapid development.

Phytoremediation has become not only a subject of interest to universities and major research centres, but it has also created a new business for contractors and consulting firms. Phytoremediation consultants are able to advise stakeholders on whether phytoremediation would be a suitable cleanup method for their sites, and contractors are able to install the selected remediation system. The U.S. market for phytoremediation was estimated at between US$30 million and US$49 million in 1999, and has since grown. Phytoremediation is studied heavily in Canada and the United States, and draws serious interest abroad. Phytoremediation

projects are underway in Ukraine, Sweden, Switzerland, Czech Republic, China, and Poland, to name a few.

Site requirements

Requirements for site conditions have not been reported. However, the size of a site is a function of the amount of contaminated soil, and the depth accessible to the plant roots.

Cost

The cost of this technology ranges between US$150/m^3 and $630/m^3 (2004 US dollar value). The key drivers of cost include:
- the area of contamination
- the degree of effort to be devoted to the cleanup, and
- the density of sampling.

Advantages and limitations

Phytoremediation has numerous advantages that are fostering acceptance on a broad scale.
- As a solar-driven system, phytoremediation takes advantage of natural plant processes, and thus lowers costs.
- Planted sites generally are more aesthetically attractive than other choices.
- Lower air and water emissions and secondary waste production makes phytoremediation a safe treatment.
- Phytoremediation controls runoff and soil erosion.
- Phytoremediation can be used in conjunction with other remediation methods and, therefore, may be more beneficial than a stand-alone technology.
- Energy costs are almost non-existent.

The primary limitations of phytoremediation include the following:
- Since remediation is primarily based on contaminant contact with plant roots, the cleanup is only as deep as the roots reach.
- A long time is required for the remediation due to time needed for plant growth.
- Plants need to be tolerant to the contaminants (phytotoxicity). Some plants are likely to perish.
- The technique is subject to local climate conditions, planting space, the seasonal nature of plants, and possible transmittance of contaminants due to surrounding creatures, thus entering the food chain and causing more contamination problems in the ecological cycle.

Bioremediation

Overview

Bioremediation usually refers to the use of microorganisms to break down complex organic contaminants into simpler compounds. The technology usually involves enhancing natural biodegradation processes by adding nutrients, and oxygen (if the process is aerobic). In-situ bioremediation is accomplished by providing electron acceptors (e.g., oxygen and nitrate), nutrients, moisture, or other amendments to soils or sediments, without disturbing or

displacing the contaminated media. In-situ bioremediation is often used in conjunction with traditional pump-and-treat and soil flushing groundwater systems, in which the treated water is amended, as required, to stimulate microbial activity. It is then re-injected into the zone of contamination.

Site requirements

Space requirements depend on the specific technology employed. In general, in-situ applications do not require large areas. Installation of infiltration galleries and wells to circulate amendment-laden water, however, requires from several hundred to several thousand square metres of clear surface area. During ex-situ applications, more open space is typically required to accommodate equipment.

Cost

The cost of bioremediation varies from US\$55/m^3 to \$360/m^3 (2005 US dollars) (USEPA 2005). Costs at the higher end mainly apply to ex-situ and mechanical bioremediation technologies. Vendor-related technologies, such as DARAMEND$^®$ and Xeonrem^{TM} (see case studies in section 4.6), incur high costs if exported.

Advantages and limitations

There are several advantages of bioremediation:
- Both in-situ and ex-situ bioremediation technologies have been shown to be successful in treating both water-soluble and relatively insoluble compounds.
- Slurry-phase bioremediation also has the advantage of allowing more precise control of operating conditions than solid-phase or in-situ applications.
- Solid-phase bioremediation and composting offer several advantages common to slurry-phase operations and other ex-situ treatment technologies.
- Composting also enriches the treated soil, providing nutrients for revegetation.
- Energy costs required for bioremediation treatment are typically less than for alternative remedial approaches.

The limitations of bioremediation include the following:
- The success of bioremediation can be affected by a variety of factors including soil and contaminant characteristics, temperature, moisture content and pH values.
- Biodegradable contaminants may undergo mineralization.
- The contaminated soil must not exceed 10 per cent (by volume) of the treated soil.
- Bioavailability of contaminants in soil can decrease with time.
- Bioremediation is slower than many other technologies and may require frequent monitoring during startup.
- Bioremediation has not proven to be effective on polychlorinated dibenzo-p-dioxins (PCDDs) CDDs/ dibenzofurans (PCDFs).
- Breakdown of contaminants may generate more toxic by-products or contaminants that are mobile.
- Ex-situ remediation practices require large surface areas to treat large quantities of contaminated soil.
- Aerobic remediation is not applicable to sites prone to flooding.

Gas Phase Chemical Reduction (GPCR)

Overview

This process is mainly known by its commercialized product, Eco Logic, which was developed in Canada. It is an alternative to incineration. In the process, hydrogen reacts with chlorinated organic compounds, such as PCBs, at high temperatures ($\geq 850^{\circ}$C) and low pressure, yielding primarily methane and hydrogen chloride accompanied by minor amounts of other low molecular weight (MW) hydrocarbons, such as benzene.

Site requirements

According to Eco Logic, the supplying vendor, the system requires a relatively level area, and approximately 40 m $\times$ 50 m, for the processing and auxiliary equipment, for a capacity of 150 tons of contaminated soil per month. Utility tanks require level surfaces or supports. The reactor system equipment sits on two mobile trailers, and a separate trailer transports the thermal desorption unit (TDU), solid feed hopper, and quench system. Cold-weather operations may inhibit efficient destruction because of the incremental amount of energy required to heat the reactor and the TDU molten metal bath. In addition, feedstock liquids may require melting prior to treatment; liquid residuals could freeze in unheated storage tanks.

Cost

The cost is reported to be between US\$500/m^3 and US\$630/m^3 (USEPA, 1994). The treatment capacity corresponding to this cost range was not specified.

Advantages and limitations

The advantages of GPCR include the following:
- The method is indiscriminate in its treatment of organic substances. It can be expected to treat pentachlorophenol (PCPs) with similar effectiveness to PCBs, hexachlorobenzene (HCB) and dioxins.
- The process requires water in its operation and therefore can process wastes with relatively high water content. This may prove to be an advantage over other thermally based processes where high water content is problematic.
- Under a reducing atmosphere the formation of dioxins is less likely to occur.

This process has several limitations:
- The process has to be preceded by a TDU when treating solid wastes. The thermal desorber will operate under a reducing hydrogen atmosphere, offering simultaneous destruction.
- Application of the TDU to irregular solids such as concrete (containing reinforcing materials) is uncertain; however, the sequencing batch vaporizer has been used to treat concrete slabs. Material handling considerations for such wastes may limit the application of the process.

Solvent Extraction

Overview

Solvent extraction is an ex-situ process in which contaminants are separated from soils, sludges, and sediments, thereby reducing the volume of waste that must be treated. In the process, the contaminated soil or waste material is brought into contact with a fluid that selectively dissolves the contaminants.

Site requirements

Typical commercial-scale units (50 to 70 tons per day) may require a total treatment area of 930 m^2 and a power supply. Water must also be available at the site.

Cost

A one-time startup (including capital) cost of solvent extraction is estimated at US$175,000 for a commercial unit. The cost of an average treatment ranges from US$125/$m^3$ to $400/$m^3$ (in 1995 US dollars) (USEPA 1995).

Advantages and limitations

The primary advantage of solvent extraction is that it can be capable of efficiently removing many different organic contaminants from a variety of soils, sediments, and sludges. This is partially due to the flexibility of solvent extraction processes. The solvent can be selected based on the target contaminants, whereas the number and duration of the extraction stages are selected based on the remediation criteria.

The disadvantages of solvent extraction are as follows:
- It produces a concentrated organic extract that is likely to require further treatment or disposal unless the contaminants can be used, recycled or incinerated after being extracted from the soil.
- In addition to the organic contaminants, the concentrated extract may also contain organically bound metals (which can co-extract with the organic contaminants) and traces of the extraction solvent.
- Soils with high moisture content need to be dried to achieve high removal rates.
- High clay content soils experience reduced treatment efficiencies.

Vitrification

Overview

Vitrification can be used to treat soil and sediment containing organic, inorganic, and radioactive contaminants. This technology uses heat to melt the contaminated soil or sediment. It then forms a rigid, glassy product when it cools, causing a reduction in the volume of the treated soil.

Organic contaminants, including PCBs, are destroyed as a result of the high temperatures used during vitrification. The destruction mechanism is either pyrolysis (in an oxygen-poor

environment) or oxidation (when oxygen is present). Vitrification can either be performed in situ or ex situ. There are conflicting reports on whether this technology should be considered as under development or well established.

Site requirements

There are very few site requirements for offsite ex-situ vitrification, since the only onsite activity is excavation. Access to the site must be available for the excavation equipment. For in-situ vitrification (ISV) systems, areas must be cleared for heavy equipment requiring access roads, automobile and truck parking lots, the ISV equipment, setup areas, and equipment sheds (AEW, 1997). The ISV system also requires electricity, which can be supplied by a utility distribution system or generated onsite by a diesel generator (McDowall et al., 2004).

Cost

This technology is characterized by very high capital and operating costs. The cost of this treatment ranges between US$500/m^3 and US$8,000/m^3 in 1997 dollars value (AEW 1997; McDowall et al., 2004). This cost includes mobilization, demobilization, site preparation, operation and maintenance (O/M), and waste disposal.

Advantages and limitations

There are two main advantages of vitrification:
- Very high destruction and removal efficiencies are achieved for all types of POPs.
- The treated soil can be reused.

Its limitations and disadvantages include the following:
- It generally involves high costs.
- The process can produce trace of dioxins.
- The process is time consuming and energy intensive.
- It requires treatment of gas emissions.

Pyrolysis

Overview

In this ex-situ process, organic contaminants are decomposed chemically by heat in an oxygen-starved environment. In practice, it is not possible to achieve a completely oxygen-free atmosphere; actual pyrolysis systems are operated with less than stoichiometric quantities of oxygen. The pyrolysis process degrades waste to produce char (or ash), pyrolysis oil and synthetic gas (called syngas). Pyrolysis is capable of destroying dioxins by decomposition and volatilization. The compounds are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash. Dioxins are known to evaporate over a temperature range of 315°C to 537°C. Oxygen plays a crucial role in the reactions of PCDD/Fs during thermal oxidation. Therefore, in addition to removal, pyrolysis may also prevent further dioxin formation, particularly of PCDDs and PCDFs in the residual material, due to the reducing atmosphere.

Site requirements

Little information is reported on site requirements. However, since pyrolysis has many similarities to incineration, site requirements are similar.

Cost

Pyrolysis technology is reported to cost between US$375/m^3 and US$500/m^3, with no information available on what is included in this cost (AEW 1997; Deuren et al., 2002).

Advantages and limitations

The advantages of this system include the following:
- It is applicable to a wide range of organic contaminants achieving high destruction and removal efficiencies.
- Some technologies such as STARTECH do not require pre-screening of soil.
- Wastes may be converted into recoverable commodities by-products.
- Pyrolysis uses less O_2 and thus air emissions tend to be lower than for incineration.

Pyrolysis has a number of limitations and disadvantages:
- Some pyrolysis technologies require specific limits of particulate feed size and material handling.
- These technologies may require pre-drying of soil to achieve low moisture content and to decrease treatment costs.
- Highly abrasive feed can potentially damage the treatment units due to wear caused by the moving particles.
- There is potential production of dioxins, furans and other hazardous compounds, especially in units that operate at very high temperatures.
- Treated media containing heavy metals require stabilization.
- Energy costs, especially for plasma reactors, are substantial.

Ball Milling/ Mechano-Chemical Dehalogenation (MCD)

Overview

Ball milling technology, commercially known as MCD, treats high-strength waste containing POPs, using mechanical energy to promote reductive dehalogenation of the contaminants. The MCD process was developed by Environmental Decontamination Ltd. Little information is available on its use in full-scale projects; however, it has been reported that it has been utilized in New Zealand (USEPA 2005).

Site requirements

No information has been published. Electrical power or diesel units are needed to run the mechanical units.

Cost

The costs associated with this technology are unknown, due to limited reporting.

Advantages and limitations

A number of potential advantages have been claimed for MCD:
- There is reduced release of contaminants due to low energy.
- The process can be readily shut down in a short period of time, further reducing the potential for release in case of an emergency or power failure.
- The low temperature operation increases safety, reducing energy consumption and the potential for formation of dioxins and other toxic organics.
- Well-established mineral processing equipment and principles are used.
- The high degree of mixing of wastes tends to break up agglomerated material.
- No gaseous emissions are produced.
- The process is likely to readily treat wastes containing a range of organic contaminants, or mixtures of organic contaminants, in one step, thus reducing waste handling and associated risks.

Although limitations have not been reported explicitly, this technology clearly has several significant disadvantages:
- Soil needs to be dried to reach a moisture content of two per cent at most.
- Pre-screening may be needed to meet the size limitations.
- The destruction efficiency is relatively lower than for other treatment technologies, and is unsuitable for highly contaminated soils.
- The milling inevitably causes the generation of fine particulates, a potential source of dust. The balls used in the milling will also undergo wear, further adding to the dust.
- The equipment is extremely noisy.

Sanitary Landfilling

Overview

Landfilling is a technique which is intended to contain the migration of POPs. Since landfilling does not normally destroy POPs, every effort must be made to prevent their migration.   Proper linings and monitoring are required to ensure that there is no leakage from the landfill containment system.   The **engineered/control landfill** can be considered as a temporary measured until destructive technologies for POPs become available for developing countries, providing greater environmental sustainability and being economically affordable.

Site requirement

Landfill sites must be selected properly. Attention must be paid to the local geological and hydro-geological situation in selecting any landfill site. Locations to be avoided include flood-hazard areas and wetlands, areas subject to heavy rainfall, highly permeable soil (i.e. silt, sand, gravel), public water supply watersheds, groundwater aquifers, recharge areas, areas with high water tables, limestone bedrock, designated parks, forests, historic areas, and wildlife refuges, and zones of high seismic-risk

Environmental impacts must be assessed for environmental impacts (i.e. air pollution, noise, water pollution, soil contamination and ecological risks), consider economic impacts also, then plan for preventive and mitigation measures.

Cost

Not available

Advantages and limitations

There are several advantages of engineered landfills:
- Many POPs are still being stored or disposed onto land, regardless of the development level of the country. A well-designed landfill has a large capacity for temporary storage and prevents migration of POPs.
- Local soil materials or waste materials with high adsorptivity and low hydraulic conductivity should be explored as possible containment barrier materials.   If appropriate for adoption, these materials can benefit the local economy and might even gain a global market for such a material for containment purposes.

Major limitations of landfills are as follows:
- POPs are not destroyed, and there is always the potential for leakage from storage tanks and the site itself.
- POPs must be kept in compatible tanks to prevent erosion.
- Monitoring of the surrounding area is needed.

4.7 COST-EFFECTIVE REMEDIATION OPTIONS FOR DEVELOPING COUNTRIES

This section focuses on two of the technologies described in the previous section — phytoremediation and bioremediation — as relatively new and potentially cost-effective remediation options for the remediation of POP-contaminated sites in developing countries. In-situ options are more economically attractive compared with ex-situ options, which involve excavation and storage of excavated material before transporting the same to ex-situ remediation facilities.

Phytoremediation appears to be suitable for superficially contaminated sites while bioremediation has proven (Williams et al., 2000) to be more economically competitive if the contaminants have migrated deep into the soil and strata, and are biodegradable. Bioremediation followed by phytoremediation of residual contaminants appear to be the most cost-effective process for contaminants amenable to biodegradation because this hierarchical approach is linked to a building up of ecological capital through phytoremediation. This approach may be particularly well-suited for developing countries with moderate tropical climates.

Bioremediation using an Aerobic/Anaerobic Cycling

Bioremediation and phytoremediation are innovative technologies with the potential to alleviate numerous pesticide contamination problems.   Before considering any bioremediation options, it should be remembered that POPs, in general, are recalcitrant and that some POPs are also refractory in nature because of their chemical structure. (The recalcitrance and refractory status of a contaminant determines its amenability to degradation, with refractory contaminants being less amenable.)   An active oxidation process, which is able to modify the complex structure, may be considered as a pre-treatment option. In addition, POPs are extremely electronegative compounds and serve as electron acceptors rather than electron donors. The degradation may occur faster in anaerobic systems where an easily-degradable carbon source can be used as an electron donor. Although it has been reported in literature (Kennedy et al., 1990; Bumpus and Aust, 1987; Safferman et al., 1995) that white-rot fungi can be used to inoculate a composing operation, large quantities of the fungus, together with a carbon source, are required to remediate a site. However, due to the very slow biodegradation ability of the fungi (Bumpus and Aust, 1987), the process may not be practically viable.

A presentation at the 1996 Air and Waste Management Association Annual Meeting discussed the results of a treatability study for pesticide-contaminated soil, which addressed six technologies including two bioremediation approaches (Frazar, 2000). Thermal desorption proved to be over 99 per cent effective at removing the contaminants. The estimated cost for this treatment was between US$ 155 and US$ 205 per ton (Frazar, 2000).   Bioremediation using an aerobic/anaerobic cycling system demonstrated the capability to destroy DDT and toxaphene from the soil (Frazar, 2000). The cost of this process was estimated to range between US$ 80 and US$ 120 per ton, which was less than that involved in thermal desorption (Frazar, 2000).

Table 4.8 shows the cost comparison of different technologies, which are usually practiced in the field (Frazar, 2000).

Table 4.8

Comparison of available technologies for the treatment of sites contaminated by pesticides

Technology	Cost Range (per m³)1 in US $	Treatment Time (months)2	Treatable Media1	Removal Efficiency1
Low Temperature Thermal Desorption	$100 to $400	0.75	Soil, Sludge and Sediment	82% to >98%
Incineration	$300 to $1,000	1	Soil, Sludge and Sediment	generally >99.99%
Bioremediation	$8.4 to $197	3.1 (ex situ)	Soil, Sludge, Sediment and Groundwater	up to 99.8%
Phytoremediation	~$80 or $60k to $100k/acre	No data	Soil, Sludge, Sediment and Groundwater	up to >80%

Source: Frazar, 2000

[1] Based on the treatment of pesticide contaminated media

[2] Based on treatment of 1,000m³ of contaminated soil contaminated with various organic compounds

Anaerobic stage of bioremediation

Under anaerobic conditions, indigenous microorganisms are capable of partially transforming the pollutant through reductive dechlorination, resulting in the replacement of chlorine atoms from POPs with hydrogen atoms. Over a very long period of time these microorganisms would completely mineralize the pollutant, but by introducing oxygen and creating aerobic conditions, the mineralization occurs much more rapidly. Unfortunately, the microorganisms that operate under aerobic conditions are not capable of catalyzing the first step. Therefore, it is necessary to cycle the contaminated soil between anaerobic and aerobic conditions.

Aerobic stage of bioremediation

Bioremediation using white-rot fungi to inoculate contaminated media is a promising technology that is currently being researched. This technology can be used both ex situ and in situ. Generally, this fungus is used to inoculate a composting process, but it does have other bioremediation applications.

Aerobic composting involves the mixing of the contaminated soil in a pile with a solid organic substrate, which serves as a carbon source for the indigenous aerobic soil microorganisms. Composting is a means for the remediation of pesticide-contaminated sitesThe soil is excavated, screened and formed into windrows or some form of pile. The soil is then supplemented with the organic substrates, nitrogen and phosphorous. Moisture, pH and redox potential are monitored while the soil is mixed on a regular basis to maintain homogeny and aeration. The piles may also be kept anaerobic, if required, by covering them with plastic sheets and encouraging the aerobic microorganisms to utilize all of the oxygen remaining underneath. Once the oxygen in the pile has been depleted, anaerobic microorganisms will become active, degrading the organic pollutants that were non-degraded by the aerobic microbial population. Figure 4.10 shows an aerobic windrow composting system.
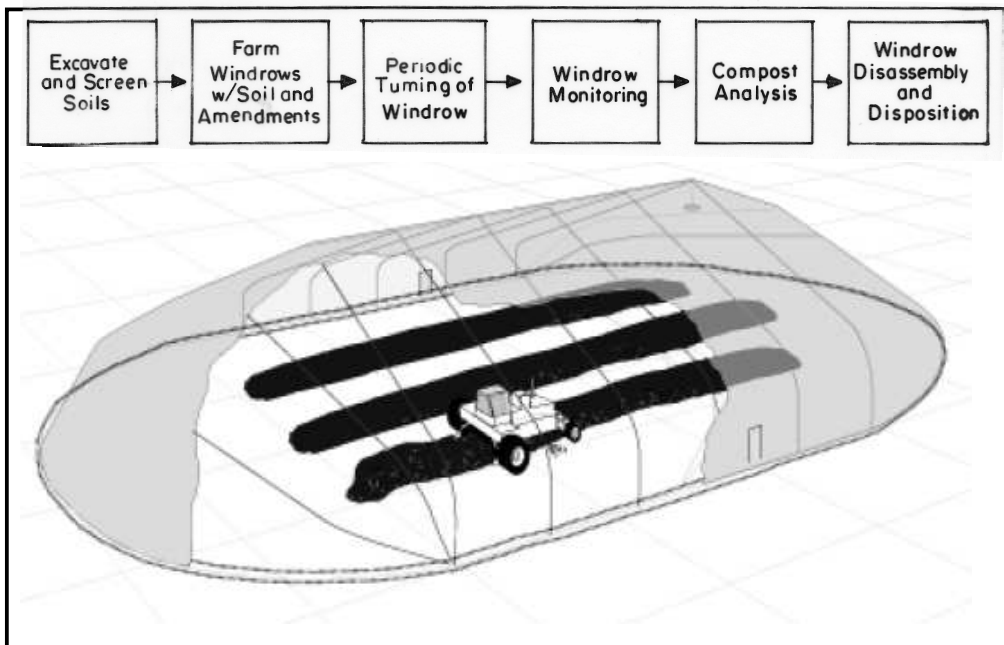
Source: Frazar, 2000.

Figure 4.10
An aerobic windrow composting system

White-rot fungi, particularly those of the family *Phanerochaete*, are becoming recognized for their ability to efficiently biodegrade toxic contaminants. Most studies focus on the ability of *Phanerochaete chrysosporium* to degrade persistent compounds, but *Phanerochaete sordida*, *Pleuotus ostreatus*, *Phellinus weirii*, and *Polyporus versicolor* have also been successful in laboratory studies (Bumpus and Aust, 1987; Safferman et al., 1995). These fungi are effective because of an extracellular enzyme that catalyzes lignin biodegradation. In order to catalyze these powerful reactions, the enzyme requires hydrogen peroxide, which is produced by the fungus. These fungi are capable of degrading chlordane, lindane and DDT, which makes them useful for the remediation of pesticide-contaminated sites (Alexander, 1999). White-rot fungi could be used to inoculate a composting operation. However, large quantities of the fungus are required to remediate a site due to the very slow nature of compound degradation (Bumpus and Aust, 1987). Other studies (Alexander, 1999) have demonstrated the ability of white-rot fungi to degrade DDT in aqueous cultures.

## Other bioremediation approaches

Land farming:

The terms *land farming*, *land spreading*, *land application* and *land treatment* are often used interchangeably to refer to the same process—a full-scale bioremediation technology where contaminated solid media, such as soil, sludge or sediment, are applied to uncontaminated soil. Mixing of the contaminated media with the soil allows the indigenous microorganisms to interact with the contaminant and degrade it. The rate of application is calculated so as to avoid concentrations that would be unsafe in soil, groundwater or crops. The size and location of the spreading operation is then chosen based upon the application rate. Finally, a cover crop may be added to the land farming operation. A cover crop allows a farmer to

continue to use these productive fields while remediation occurs, and it may enhance rhizosphere degradation. Often it is necessary to add nutrients in order to enhance biodegradation by these indigenous organisms. In addition, it is important to monitor soil moisture and oxygen levels. Although the land farming process is slow, it is a very low-cost technology, which makes it attractive to small waste generators, such as farmers.

Land spreading has been used successfully throughout the United States, particularly in the Midwest, to remediate a variety of different pollutants. It is the most widely used ex-situ bioremediation treatment process (USEPA, 1997). Before farmers can begin land spreading, they must obtain a permit and fully outline their intentions, including the quantity of contaminant and the soil characteristics of the land where it will be applied. When land spreading, it is required that all guidelines on the label, including rate of application and season of application be followed. The state of Wisconsin requires the oversight of the land spreading process by a certified applicator. As pesticides reach the soil through normal application, land spreading at application rates generally does not require a lined bed. However, land spreading of pesticides at significantly higher concentrations or land spreading of other hazardous wastes occurs on a lined bed to collect leachate.

A typical system for the land treatment of hazardous wastes is shown in Figure 4.11. Land spreading of some hazardous compounds may result in their volatilization, which necessitates a cap for the system to control emissions.
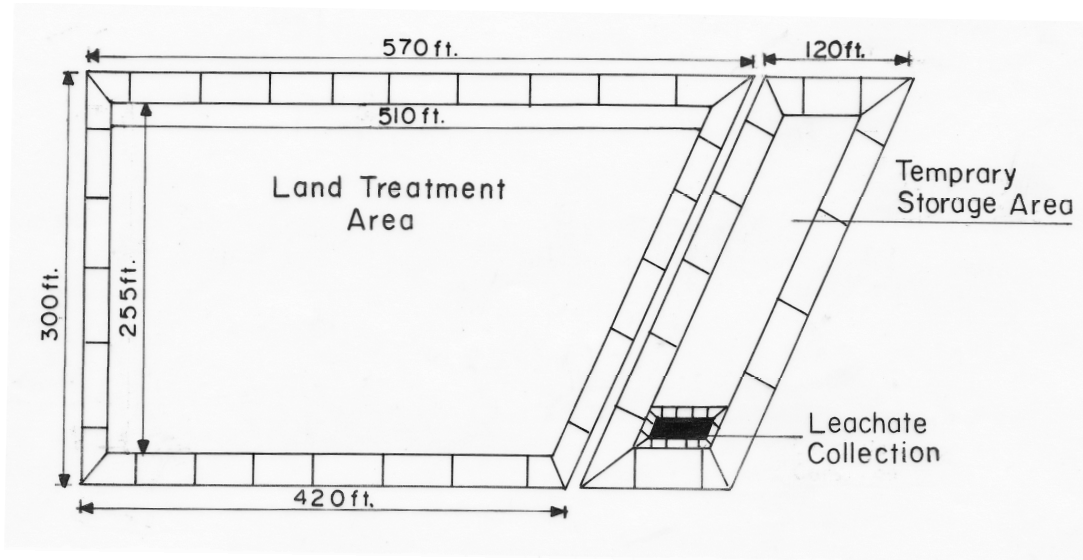
Source: Frazar, 2000
Figure 4.11
Typical lined-bed land treatment setup for the remediation of hazardous wastes

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Bioventing and biosparging:

Bioventing and biosparging are very similar in-situ processes. Both methods involve the introduction of oxygen into permeable soil to increase the activity of aerobic microorganisms. Bioventing introduces the O_2 to the vadose, or unsaturated zone, while biosparging introduces O_2 below the water table into the saturated zone. Neither of these processes is suitable for compounds, which may volatilize too quickly. Biosparging can force volatile contaminants out of the water table and up into the unsaturated zone, from which the vapours can be recovered Because of this, it is necessary to monitor off gases. Biosparging also introduces O_2 to the saturated zone, which will increase the rate of biodegradation. These procedures have not been used frequently with chlorinated pesticide-contaminated sites because of slow degradation of these pesticides.

Natural attenuation:

Monitored natural attenuation is the remediation of contaminated media by indigenous microorganisms without active treatment. This remediation process requires a longer timeframe to reach remediation goals than active bioremediation methods.

Phytoremediation

Plants are often capable of the uptake and storage of significant concentrations of some heavy metals and other compounds in their roots, shoots and leaves. This process is referred to as phytoextraction. The plants are then harvested and disposed of in an approved manner, such as in a hazardous waste landfill.

Phytotransformation occurs when plants transform organic contaminants into a less toxic, less mobile or more stable form. This process includes phytodegradation, which is the metabolism of the organic contaminant by the plant enzymes, and phytovolatilization, which is the volatilization of organic contaminants as they pass through the plant leaves.

Phytostabilization immobilizes the contaminants and reduces their migration through the soil by absorbing and binding leachable constituents to the plant structure. This process effectively reduces the bioavailability of the harmful contaminants. Almost any vegetation present at contaminated sites will contribute to phytostabilization (Arthur and Coats, 1998).

At the soil-root interface, known as the rhizosphere, there is a very large and very active microbial population. Often the plant and microbial populations provide needed organic and inorganic compounds for one another. The rhizosphere environment is high in microbial abundance and rich in microbial metabolic activity, which has the potential to enhance the rate of biodegradation of contaminants by the microorganisms. Generally, the plant is not directly involved in the biodegradation process. It serves as a catalyst for increasing microbial growth and activity, which subsequently increases the biodegradation potential. However, the rhizosphere can be limited in its remediation potential because it does not extend far from the root. This process is often referred to as plant-assisted bioremediation.

Table 4.9 summarizes the results and duration with respect to experimental design involved in the remediation of certain pesticides (both POPs and non-POPs).

Table 4.9
Summary of selected bench-scale and small-scale field experiments

Experimental Design	Contaminant(s)	Experiment Duration	Results / Remediation Efficiency
Bioremediation Studies			
White Rot Fungus biodegradation	DDT	30 days	69% of DDT Degraded 3% mineralized to CO_2
White Rot Fungus biodegradation – several species of fungi	DDT	30 days	Species Dependent. Approx. 50% degradation. Approx. 5% to 14% of DDT mineralized to CO_2
White Rot Fungus biodegradation – Phanerochaete chrysosporium	Mirex, aldrin, heptachlor, lindane, dieldrin, chlordane	21 days	Chlordane: 9% to 15% metabolized to CO_2 Lindane : 23% metabolized to CO_2. No other compounds were significantly degraded.
Pesticide rinsewater absorbed by peat moss, followed by composting	Malathion, captan, lindane, diazinon.	Data Not Given	<2% of starting concentrations remained after treatment
Biofilter used to remove contaminants from a liquid stream	2,4-D, DDT	168 hrs	2,3-D: 99% removal. DDT: 58% to 99% removal.
Laboratory scale soils slurries and trickling biofilters for treating cattle dip vat wastes	coumaphos (an organophosphate)	7 to 10 days	Most soil slurries showed rapid mineralization. Biofilters decreased coumaphos concentration. From ~ 1200mg/L to 0.02-0.1mg/L.
Field scale trickling biofilters for the treatment of cattle dip vat wastes followed by biodegradation in soil	coumpahos	30 days	Biofilter reduced concentration. From 2,000 mg/L to 8-10mg/L after 29 days. Vitamin supplements increased coumaphos degradation. Treated coumaphos degraded further in soil.
Biofilm and biofilm/activated carbon columns used to treat pesticide wastewater	Variety of pesticides, including organophosphates and triazines	Greater than 4 months	Biofilm alone: 88% to 95% reduction. Biofilm/ Activated Carbon: >99% reduction and reduction in COD. Simazine was the only pesticide resistant to treatment.
Five different wastewater treatment processes	2,4-D, lindane, heptachlor	8 months	The facultative lagoon was the most effective process removing 73% of 2,4-D, 80% of Lindane and 62% of heptachlor.
Varioius oxic/anoxic cycling and oxic remediation methods using the DARAMEND™ technology	Isomers of hexachlorocyclohexane	45 days	Many different variations. Anaerobic/aerobic cycling was the most effective process; however, aerobic treatment did work. Range of remediation efficiency: 41% to 96%.
Contaminated groundwater bioremediation using a water treatment plant	Chlorobenxenes, chlorophenols, BTXE-aromatics and hexachlorocyclohexanes	4 weeks	Degradation rate was highly specific to the position of chlorine substituents. Rapid dechlorination was noticed w/ monochlorobenzene, and ortho-and meta-substituted di- and trichlorobenzenes.
Anaerobic reductive dechlorination	Hexachlorobenzene	37 days	Complete degradation. Approx. 79% transformed to 1,3,5-trichlorobenzene
Combination of land farming and biostimulation	Alachlor, metolachlor, trifluralin and atrazine	60 days	80 to 85 alachlor reduction in contaminated soil. Complete reduction in alachlor-sprayed plots. Alachlor, metolachlor and trifluralin were all recovered least in cornmeal amended soil.
Anearobic biodegradation field studies with nutrient supplements	Toxaphene	Several studies varying from 14 days to 21 months	Navajo Vats Site: 58% to 86% reduction after 3 to 12 months. Ojo Caliente Dip Vat Site: >70% reduction after 14 days. Sanders Aviation Site: 94% to 95% reduction after 7 months

Experimental Design	Contaminant(s)	Experiment Duration	Results / Remediation Efficiency
Phytoremediation Studies			
Examined the use of the herbicide-tolerant species, Kochia, to enhanced rhizosphere degradation	Atrazine, metolachlor and trifluralin	14 days	Enhanced microbial degradation was observed in rhizosphere. 45% reduction of atrazine. 50% reduction of metolachlor and 70% reduction of trifluralin.
Combination of composting and planting	Many present. Major pesticides; metoalchlor, pedimethalin, trifluralin	40 days	50:50 mix of contaminated soil and compost maximized plant growth and minimized dilution. Rhizosphere had greatest bacterial activity w/ contaminated soil/ uncontaminated soil mix. Contaminated / Uncontaminated soil mix results in >95% metolachlor reduction
Phytoremediation using three different types of plant	Organophosphates; malathion, demeton-methyl, ruelene.	8 days	Species Dependent. mathion: >83% reduction. demeton-s-methyl: >78% reduction. Ruelene: no reduction up to 58%
Phytoremediation using four different types of plant	Aldrin, Dieldrin	3 years	Species Dependent. Significant incorporation in plant tissue concentration of both pesticides. Spikerush showed greatest incorporation.

Source: Frazar, 2000.

Example: Case Studies

The following two case studies (Case study 1 and Case Study 2) are examples of using bioremediation technology for POPs contaminated site remediation. As discussed above, both studies encompass composting processes which cycle between aerobic and anaerobic conditions

Case study 1 - Daramend™ process

Location
The Novartis site in Cambridge, Ontario was used as a warehouse and pesticide formulation facility beginning in 1972.

Contamination to be remediated
The contaminant of concern at this site is metolachlor, which is a chlorinated herbicide. Prior to treatment the concentration of metolachlor was 170 mg/kg. Other tests of the contaminated soil showed that concentrations of 2,4-D and atrazine were also present at the site (USEPA, 2000).

Quantity and duration
During this demonstration 200 tons of contaminated soil were treated over an 18-month period. This technology demonstration was also a part of USEPA's SITE program.

Approach
The Daramend™ process was developed by W.R. Grace & Company (1999) and is a composting process that cycles between aerobic and anaerobic conditions. The demonstration at the Novartis site was conducted between March 1996 and September 1997. Three plots were designed to test the effectiveness of the Daramend™ technology: Plot A was the main treatment plot, Plot B was the high metolachlor concentration test plot and Plot C was the static control plot (Frazar, 2000). A greenhouse was constructed that covered all three treatment plots. For the anaerobic cycle, the Daramend™ amendments were mixed with the

excavated soil, which was then irrigated and covered with a tarpaulin.

The patented Daramend™ amendment consists of both organic and inorganic material. The organic material is fibrous and generally comes from plant matter (Seech et al., 1995). It serves as a source of organics for the aerobic microorganisms that consume oxygen, creating an anaerobic environment (Seech et al., 1995). The inorganic amendment consists of multivalent metals that are capable of being oxidized and reduced. They serve as electron donors and acceptors for the anaerobic microorganisms (Seech et al., 1995). For the aerobic cycle during this demonstration, the tarpaulin was removed and the soil was tilled twice a week (Frazar, 2000). The soil was hand tilled in the high Metolachlor plot, which resulted in only the top 30 cm being tilled rather than the full 60-cm depth (Frazar, 2000). No amendments were added during the aerobic cycle. The treatment lasted for 10 anaerobic/aerobic cycles (Frazar, 2000).

Monitoring of remediation
The soil was analyzed for metolachlor using High Performance Liquid Chromatography (HPLC) at days 0, 2, 7, 98, 208, 306, 454, and 565 of the treatment (Frazar, 2000). On day 0 and day 565 (the first and last days), the soil was also analyzed for 2,4-D, dinoseb, atrazine, chloride and selected metals. 2,4-D was reduced from an initial concentration of 3.7 mg/kg to below the analytical detection levels (Frazar, 2000). Dinoseb was not detected at any point before, during or after the treatment (Frazar, 2000). Atrazine was reduced from 17 mg/kg to a concentration below the detection level (Frazar, 2000). In the main treatment plot, metolachlor was reduced from a concentration of 67 mg/kg to a final concentration that was below the detection level of 1 mg/kg, which corresponds to greater than 98.5 per cent removal efficiency (Frazar, 2000). In the high metolachlor plot, the initial concentration was 170 mg/kg, which was reduced to a concentration of 38 mg/kg following treatment, equating to a removal efficiency of approximately 78 per cent (Frazar, 2000). However, only the top 30 cm of the soil was tilled in this plot, which resulted in incomplete mixing. The average concentration of metolachlor in the top 30 cm of the soil was 11.8 mg/kg, which equates to a 93 per cent removal efficiency (Frazar, 2000). In the control plot metolachlor concentrations did not decrease.

Cost of remediation
Based upon this demonstration, Grace projects a cost of approximately US$73,000 for the remediation of the remaining 600 tons of contaminated media at the Novartis site (Frazar, 2000). This estimate equates to approximately US$120/ton. According to Grace, a full-scale remediation of 2,500 to 5,000 tons of waste would cost approximately US$52/ton to US$81/ton, depending upon site-specific conditions (Frazar, 2000). This technology appears promising for the remediation of both metolachlor and atrazine.

Other applications of the Daramend™ process
Patents have been issued to W.R. Grace & Co. for the Daramend™ process This process has been used in a technology demonstration at a chemical manufacturing plant contaminated with chlorinated pesticides in Ontario, Canada (Raymond, 2000). According to the technology developer, DDT, DDD, DDE, 2,4-D and 2,4,5-T were reduced from 250 tons of contaminated soil by 99.5 per cent.

At a site in Charleston, South Carolina in the United States, the Daramend™ process was used successfully in an in-situ pilot-scale demonstration to remediate toxaphene and DDT (Grace & Co., 1999) According to the technology developer, toxaphene was reduced by 98

per cent and DDT was reduced by 90 per cent from contaminated soil. An attempt has also been made to remediate a toxaphene-contaminated Superfund site in Montgomery, Alabama (Frazar, 2000).

Case Study 2 - Xenorem™ technology

Location

The Xenorem™ process was developed by Stauffer Management Company, which is a subsidiary of the Astra Zeneca Group PLC.   From 1953 until 1986 the Stauffer Chemical Company site located in Tampa, Florida in the United States served as a facility for the manufacture and distribution of organochloride and organophosphate pesticides. From 1953 until 1973, waste materials were disposed of on site by either burial or by small incinerator (Record of Decision Abstract, 2000). Site investigations revealed that pesticides were present in soils, groundwater, surface water and pond sediments (Record of Decision Abstract, 2000). Soils were tested for the presence of 32 different pesticides, several of which are classified as POPs.

Initially, low temperature thermal desorption was chosen to remediate the site at an approximate treatment cost of US$130/m^3 (Frazar, 2000). This cost did not include setup and other infrastructure costs. However, the historic usage of this site as a pesticide manufacturing facility left a variety of compounds in the soil that made thermal desorption a difficult technology to safely implement (Frazar, 2000). Coupled with the need for expensive emissions treatment equipment, this raised the final cost of using low temperature thermal desorption to approximately US $500/m^3 (Frazar, 2000).

Contaminations to be remediated

DDE, DDT, DDD, dieldrin, chlordane and toxaphene were the major pesticides targeted for this case study.

Quantity

Bioremediation using the Xenorem™ process was chosen as the means to remediate 1,000 m^3 - soil as a technology demonstration (Frazar, 2000).

Approach

The process involved the construction of composting windrows using contaminated soil and solid amendments. Although the process described here used three unspecified amendments, the Xenorem™ patent states that preferred amendments include agricultural wastes and municipal waste sludges (Bernier et al.,1997). Typically, the amendments will also include bulking agents, such as grass, sawdust or peat (Frazar, 2000). Surfactants may be added to the amendments in order to make the DDT more accessible to the soil microorganisms (Bernier et al., 1997). Indigenous microorganisms consumed the available oxygen and the pile was covered with tarpaulin in order to create an anaerobic environment (Frazer, 2000). Over the course of treatment, moisture, organic matter, inorganic composition, and pH were all monitored (Frazer, 2000).

Application of the Xenorem™ process at the Stauffer Chemical Company in Tampa, Florida began with the excavation and screening of the contaminated soil. The soil was then formulated into windrows inside a warehouse (Frazar, 2000). Due to this site's proximity to residential areas, it was necessary to install an odour abatement system (Frazer, 2000). Covering the pile with a tarpaulin created anaerobic conditions. Redox potential was

maintained below -200mV (Frazar, 2000). Aerobic conditions were created by removing the tarpaulin and either mixing the soil or injecting compressed air into the pile at regular intervals (Frazer, 2000). During the aerobic phase, the redox potential was maintained above 100mV (Bernier et al., 1997). At the beginning of the treatment, Amendments A and B were added to the soil that comprised 40 per cent and five per cent of the total pile volume, respectively (Frazer, 2000). At weeks 14 and 22, Amendment A was again added to the pile, but at these points in time Amendment A was only 20 per cent of the total pile volume (Bernier et al., 1997). At week 33, Amendment A was added again, comprising 40 per cent of the pile volume. Finally, in week 48, Amendments A and C were added to the pile that comprised 40 per cent and five per cent of the total pile volume, respectively (Frazer, 2000). Prior to the addition of amendments at weeks 33 and 48, a portion of the growing pile needed to be removed due to warehouse size restrictions (Frazer, 2000). Treatment time was approximately double that required in order to achieve cleanup goals, to allow for development of amendment evaluations and process control strategy optimization at the commercial scale (Frazer, 2000).

Monitoring of remediation
Concentrations of DDD, DDT, and toxaphene were reduced by more than 90 per cent (Frazer, 2000). Chlordane concentrations were reduced by slightly less than 90 per cent (Frazer, 2000). Toxaphene by-products present in the contaminated soil were reduced by 91 per cent (Frazer, 2000). Treatment brought concentrations of DDE, DDT, and dieldrin below target levels for the cleanup of this site (Frazer, 2000). Chlordane, DDD and toxaphene did not meet the remediation goal (Frazer, 2000). The remaining contaminants were not present in high enough concentrations to be of concern during the remediation planning (Frazer, 2000). With higher quality amendments and better mixing equipment, it may be possible to reduce treatment time and increase the remediation efficiency.

Cost of remediation
Stauffer Management Company provided a typical cost estimate of US$192/m^3, which covers complete project costs including the use of an environmental contractor, and infrastructural and site restoration (Frazer, 2000). The variable cost of treatment is a small fraction of this overall project cost. However, the Stauffer Chemical Company Site had higher than average costs due to its residential location and the need to tightly restrict noise and air pollution. The Xenorem™ is currently being used to remediate the remaining 16,000 m^3 of contaminated soil.

Other applications of the Xenorem™ process
The Xenorem™ process was granted several U.S. patents and is currently licensed to several environmental engineering firms, including one firm remediating a U.S. Air Force base and another remediating a site in New Zealand (Frazer, 2000). Based on the Xenorem™ technology, a bioremediation centre was established.

The Xenorem™ technology was used to treat contaminated soil at the Helena Chemical Company in Tampa, Florida in a similar manner similar to that used at the Stauffer Management Company site. The Helena site is a Superfund site and a former pesticide formulation plant that has been in operation since 1929 (Frazer, 2000). The pesticides of concern at this site include aldrin, chlordane, heptachlor, dieldrin, DDT, DDD, and toxaphene, which are pesticides named on the United Nations Environment Programme (UNEP) list of POPs. This technology has achieved 70 per cent destruction of toxaphene at this site in only six weeks.

4.8 POST-REMEDIATION MONITORING

After the site has been remediated, there must be verification that it meets the regulatory requirements. This process is called post-remediation monitoring, or "post-monitoring". Basically, the procedures are similar to those described in the detailed site investigation (see Module 2), but are carried out to a lesser extent. Soil, sediment or water samples must be collected from the previous sampling locations, a laboratory analysis conducted, and then comparisons made to the permissible levels of the contaminant of concerns. The levels must be below the permissible levels. Very often, a site requires long-term monitoring of its groundwater quality using monitoring wells and sediment quality by chemical analysis. The requirements for demonstrating compliance in the section below are relevant for both small and large sites, whereas the discussion of development of a Monitoring Plan is specifically for very large sites such as Superfund sites in the United States.

If the remediation management outcome does not meet the regulatory criteria, then the site will still be considered contaminated. At that point, the detailed site investigation will have to be repeated.

Demonstration of Regulation Compliance

The purpose of demonstration of the regulation compliance section is to provide a mechanism by which a site's owner/manager can verify to regulatory agencies that:
- appropriate and acceptable standards have been complied with and that compliance can be reasonably expected to continue in the future;
- any and all remedial measures required by the regulatory agencies have achieved their intended purpose; and
- appropriate institutional and technological controls, or monitoring mechanisms, have been successfully put in place.

Requirements for demonstrating compliance with soil standards

These requirements include the following:
- For the standards being applied, the demonstration of compliance should be at the point of compliance or at the point of exposure relating to background standards, generic soil quality standards from regulatory agencies, or site-specific standards approved by regulatory agencies.
- Minimum sample numbers must be provided to demonstrate compliance with the approved standards, as required by the regulatory agencies.
- Sampling locations for demonstration of compliance should be selected in a systematic or random fashion to be representative, both horizontally and vertically, of the volume of soil being evaluated for compliance
- Sampling for the purposes of demonstrating compliance must be conducted after completing site assessment activities and after the implementation of the applicable remedial measures.
- Demonstration of Quality Assurance (QA) and Quality Control (QC) processes must be employed to ensure that all activities and collected data are technically sound, statistically valid and properly documented.

Requirements for demonstrating compliance with groundwater standards

These requirements include the following:
- For the standards being applied, the demonstration of compliance should be at the point of compliance or at the point of exposure relating to background standards, generic groundwater quality standards from regulatory agencies, or to comply with site-specific standards approved by regulatory agencies.
- Monitoring wells installed for the purpose of demonstrating compliance must be of sufficient number and appropriate location to evaluate all hydrologic strata of concern. Generally, monitoring wells should be placed in locations surrounding the suspected sources of groundwater contamination. Although most wells should be downgradient from the suspected source, upgradient and lateral locations are required for both background assessment and for evaluation of the geological setting.
- Sampling for the purposes of demonstrating compliance should be conducted after the completion of site assessment activities and implementing the applicable remedial measures.
- Demonstration of Quality Assurance (QA) and Quality Control (QC) processes must be employed to ensure that all activities and collected data are technically sound, statistically valid and properly documented.

Requirements for demonstrating compliance with a background standard

These requirements include the following:
- To apply a background standard, the applicant must demonstrate to the regulatory agencies that any background contamination at the site is due to widespread or naturally occurring contamination.
- For soil, the minimum sample number to determine the background standard is generally 10 (unless a lesser number is approved by the regulatory agencies).
- For groundwater, a minimum of 12 locations must be sampled in the background reference area. In areas involving more than one hydrologic strata, more samples may be required.
- Demonstration of Quality Assurance (QA) and Quality Control (QC) processes should be employed to ensure that all activities and collected data are technically sound, statistically valid and properly documented.

Submission of report(s)

The report should include the following main sections:
- Introduction
- Background
- Site Description
- Details and Results of Field Investigation
- Details and Results of Laboratory Investigation
- Data Evaluation and Discussion
- Site Assessment
- Overall Conclusions and Recommendations

Review and approval

The final report is subject to review and approval by the appropriate regulatory agencies.

Developing a Monitoring Plan

As mentioned earlier in this section, the Monitoring Plan process normally applies to very large contaminated sites.

Monitoring overview

Monitoring a site should outline the why, what, when, who and how of the monitoring activities.

Process for developing a monitoring plan

This section outlines a six-step process (USEPA, 2004) that can be used to develop and document a Monitoring Plan (Figure 4.12). This process relies on the use of a data quality objective (DQO) process (USEPA, 2000a).

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┌─────────────────────────────────────────────┐
│ 1.    Identify Monitoring Plan Objectives    │
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                      ↓
┌─────────────────────────────────────────────┐
│ 2.    Development of Monitoring Hypothesis   │
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│ 3.    Formulate Mentoring Decision Rules     │
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│ 4.    Design the Monitoring Plan             │
└─────────────────────────────────────────────┘
                      ↓
┌──────────────────────────────────────────────────┐
│ 5.    Conduct Monitoring Analyses and Characterize │
└──────────────────────────────────────────────────┘
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┌─────────────────────────────────────────────┐
│ 6.    Establish the Management Decision      │
└─────────────────────────────────────────────┘
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┌─────────────────────────────────────────────┐
│              Documentation                   │
└─────────────────────────────────────────────┘
```
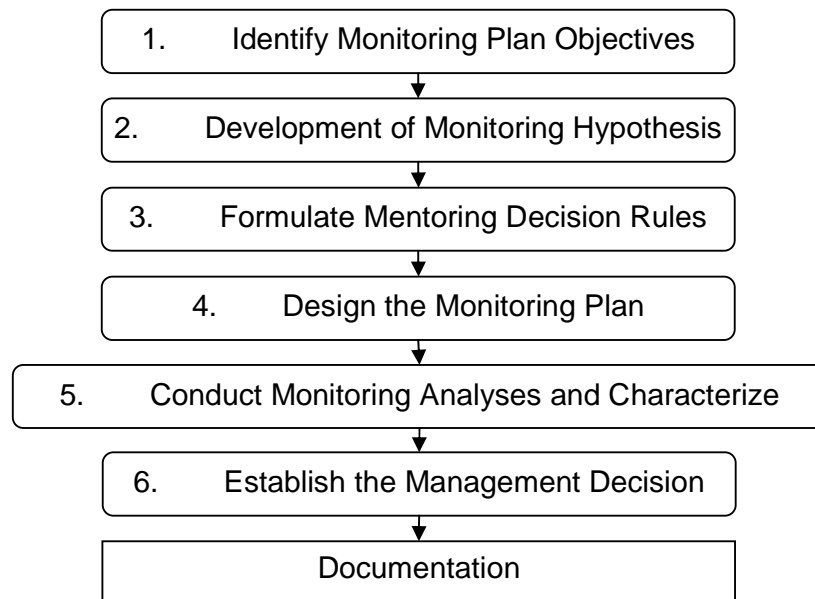
Figure 4.12
Process for developing a monitoring plan

Step 1: Identify monitoring plan objectives

Evaluate site activities
- *Identify the objective of the activities.* Activities associated with, but not directly related to, the objectives of the site activity should be identified. For example, mitigating measures should be identified and evaluated to determine whether they need to be included as components of the Monitoring Plan.
- *Identify the activity endpoints*. Each site activity has a unique set of physical, chemical, and/or biological endpoints that are the targets of the site activity. These endpoints should be considered when formulating the monitoring objectives.
- **Identify the activity mode of action.** The mode of action for each activity defines how that activity is expected to attain its desired outcome and relates the activity endpoints to the objectives.

Identify monitoring objectives
The purpose of the Monitoring Plan is to demonstrate that a specific activity outcome has been, or is being, met within some particular timeframe, and to thus support one or more of the management objectives. Table 4.10 (USEPA, 2004) presents examples of different types of site activities and potential monitoring objectives that have been found to be helpful in developed countries.

Table 4.10
Example Monitoring Objectives for Different Site Activities

Site Activity	Monitoring Objectives
Sediment capping to reduce contaminant exposure and migration	Demonstrate that the cap is effective in reducing exposure — Has the desired degree of exposure reduction been attained? Demonstrate that contaminants have not migrated off site — Are contaminants at off-site locations below preliminary remediation goals? Demonstrate that mitigation measures enacted during remedy implementation are successful — Are mitigation measures effective in controlling potential impacts of remedy implementation and operation?
Wetland mitigation	Demonstrate success of wetland mitigation — Have mitigation activities achieved a desired wetland function?
Storm water outfall compliance with National Pollutant Discharge Elimination System (NPDES) permit requirements	Demonstrate that outfall water concentrations do not exceed levels specified in an NPDES Permit — Are desired water concentrations being attained?
Bioremediation to reduce soil contaminant concentrations	Demonstrate effectiveness in contaminant concentration reduction — Has a desired contaminant level been attained?
Groundwater treatment with short-term institutional controls to prohibit groundwater use until cleanup goals have been met	Demonstrate that treatment is effective in reducing contaminant concentrations — Have contaminant groundwater concentrations been reduced to desired levels? Demonstrate that institutional controls are prohibiting groundwater use during treatment — Has groundwater use stopped?

Source: USEPA (2004)

Stakeholder awareness
The early involvement of stakeholders is important so that their issues and concerns can be identified. This involvement should occur before the objectives, decision rules, and study

design of the Monitoring Plan in order to limit future disagreements about the specific design of the Monitoring Plan and thereby avoiding project delays.
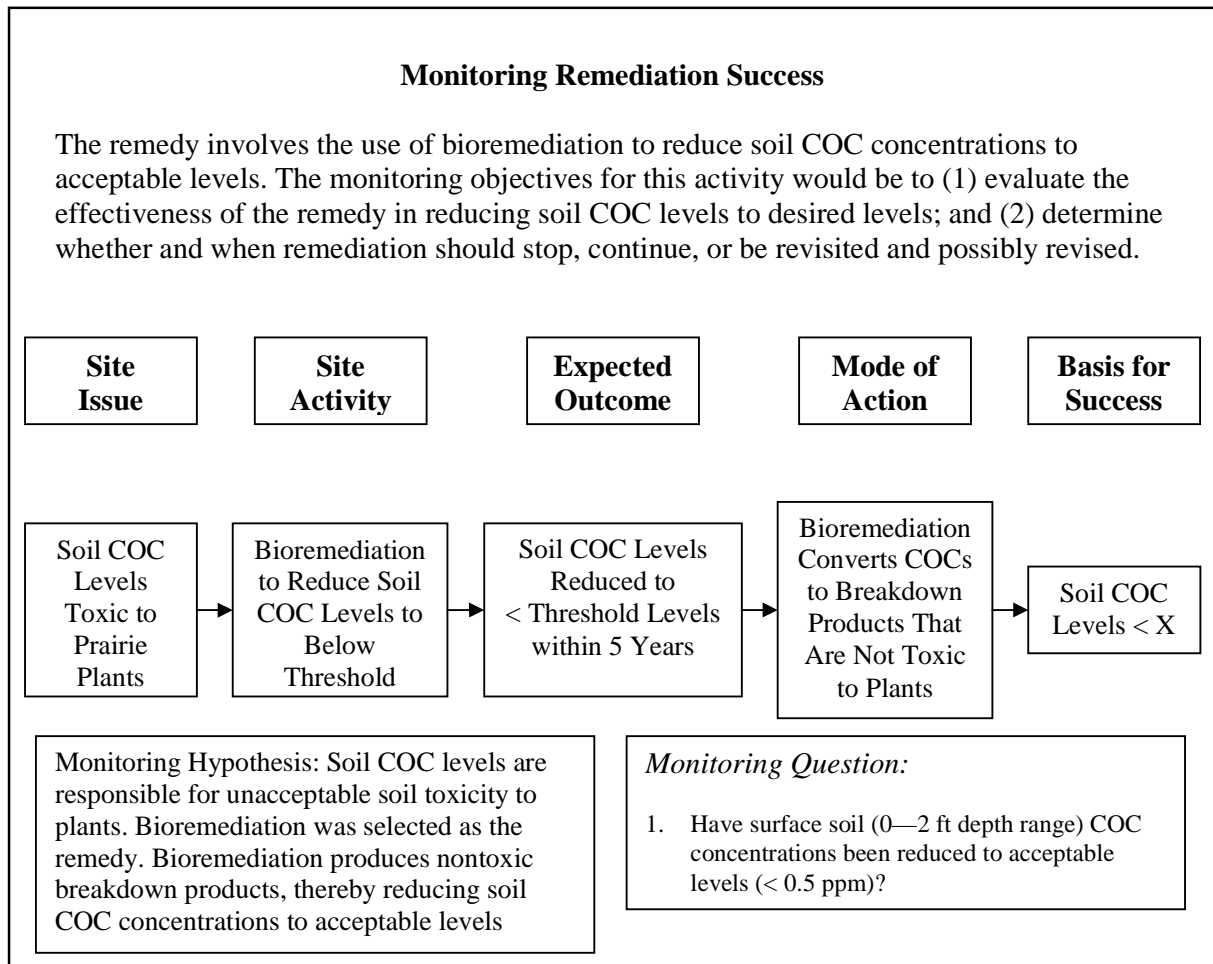
Scientific Management Decision Point (SMDP)
The purpose of the SMDP is to document a decision that identifies one or more monitoring objectives that best address the site activity.

Step 2: Development of monitoring hypotheses

Develop monitoring conceptual models and monitoring hypotheses
The monitoring conceptual model consists of a series of working hypotheses that identify the relationships between each site activity and its expected outcome. It also serves as the basis for the monitoring hypotheses and questions. Development of monitoring hypotheses may be aided by a monitoring conceptual model. These provide the basis for deciding whether an activity has reached its stated objective(s). Figure 4.13 illustrates an example of simple monitoring hypotheses and questions for a hypothetical remediation.

Monitoring Remediation Success

The remedy involves the use of bioremediation to reduce soil COC concentrations to acceptable levels. The monitoring objectives for this activity would be to (1) evaluate the effectiveness of the remedy in reducing soil COC levels to desired levels; and (2) determine whether and when remediation should stop, continue, or be revisited and possibly revised.

Site Issue	Site Activity	Expected Outcome	Mode of Action	Basis for Success
Soil COC Levels Toxic to Prairie Plants	Bioremediation to Reduce Soil COC Levels to Below Threshold	Soil COC Levels Reduced to < Threshold Levels within 5 Years	Bioremediation Converts COCs to Breakdown Products That Are Not Toxic to Plants	Soil COC Levels < X

Monitoring Hypothesis: Soil COC levels are responsible for unacceptable soil toxicity to plants. Bioremediation was selected as the remedy. Bioremediation produces nontoxic breakdown products, thereby reducing soil COC concentrations to acceptable levels

Monitoring Question:

1. Have surface soil (0—2 ft depth range) COC concentrations been reduced to acceptable levels (< 0.5 ppm)?

Source: USEPA (2004)
Figure 4.13
A monitoring conceptual model, a monitoring hypothesis, and associated monitoring questions for a remedial action addressing contaminated soil

SMDP

The outcome of Step 2 is the identification of monitoring hypotheses and questions specific to the site activity and the development of a monitoring conceptual model that identifies the relationships between the site activity and its expected outcome. These comprise the SMDP for Step 2. The purpose of the SMDP is to document a decision regarding monitoring hypotheses, questions, and the conceptual model.

Step 3: Formulate mentoring decision rules

Formulate monitoring decision rules

Preliminary monitoring decision rules are developed that take the form of generalized DQO decision rules. A decision rule is an "if... then..." statement that defines the conditions that would lead the decision-maker to choose an action. In other words, it establishes the exact criteria for making a choice between taking or not taking an action. In a monitoring program, the decision rules should establish the criteria for continuing, stopping, or modifying the Monitoring Plan and/or the site activity. In general, there are four main elements of a monitoring decision rule:

- the parameter of interest
- the expected outcome of the site activity
- an action level (specifying the basis on which a monitoring decision will be made)
- alternative actions (giving the monitoring decision choices for the specified action level)

The preliminary decision rules should be stated in general terms with regard to these elements. Note that the preliminary decision rule does not identify specific bounds for the action level, such as an acceptable toxicity level, a soil contaminant level, or a temporal component for the results. These specifics should be developed during the design of the Monitoring Plan (see Step 4).

Figure 4.14 is an example (USEPA, 2004) of preliminary decision rules for a bioremediation project. In this example, the specific monitoring study is a measurement of soil COC concentration, the study endpoint is COC concentration, the action level is a COC level at or below a target concentration, and the alternative actions are to cease or continue remediation and monitoring.

Preliminary Decision Rules for a Bioremediation Project: Example

A preliminary decision rule associated with a remedial action to reduce soil COC levels may be stated as follows: "If the monitoring results indicate that bioremediation has reduced soil concentrations to acceptable levels, then the bioremediation will be considered to have reached its objectives and no further remedial action or monitoring will be necessary. Otherwise, further action in the form of continued or revised remediation and monitoring will be necessary." In this example, the preliminary decision rule identifies the parameter of interest (soil COC levels), the site activity (bioremediation), the action level that will serve as the basis for a decision (an acceptable soil COC level), and the alternative actions (conclude bioremediation and monitoring, or continue remediation and monitoring).

Source: USEPA (2004)

Figure 4.14

An example of the preliminary decision rules for a bioremediation project.

SMDP
Preliminary monitoring decision rules have been developed that define the conditions that allow the decision-maker to choose among alternative actions related to the monitoring program and the site activity. These preliminary decision criteria represent the SMDPs for Step 3. The decision should be formally recorded as a memorandum or as a letter to file.

Step 4: Design the monitoring plan

Identify data needs
A variety of data may be necessary to test the monitoring hypotheses, to answer the monitoring questions, and ultimately to support a management decision. These data may be chemical, physical, and/or biological in nature, depending on the hypotheses and questions, as well as the decisions to be made.

Determine Monitoring Plan boundaries
The monitoring boundaries represent the "what, where, and when" aspects of the Monitoring Plan. In defining these boundaries, the monitoring team should answer the following questions:
 - ➢ What data are needed?
 - ➢ How should samples be collected (methodology, as well as discrete or composite)?
 - ➢ Where should the monitoring samples be collected?
 - ➢ When should the monitoring samples be collected?
 - ➢ How long should the sampling continue?
 - ➢ How often should sampling campaigns be carried out?

Idenitfy data collection methods
For a specific data need there may be a variety of approaches to collecting the necessary data; some are likely to be more costly or difficult to implement than others. It is not necessary to identify specific sampling designs at this stage of the study design. Specific sampling designs are developed during optimization of the data collection design (see Step 5). Rather, at this point, data collection methods are identified that may be appropriate to collect the required data, and a preliminary determination is made of the feasibility of using these approaches to collect the data with the required characteristics and within the required time and cost constraints.

Identify data collection methods
Monitoring is the collection and analysis of repeated observations and/or measurements to evaluate changes in condition and progress toward meeting a management objective. Analysis of the monitoring data may require some form of statistical analysis. Use of an appropriate statistical method can help support or refute the monitoring hypotheses and thus help answer the monitoring questions. A variety of statistical tests may be employed to evaluate the monitoring data. The selection of the statistical approach should be based on how well the assumptions of the test are met and tied closely to the monitoring objectives, hypotheses and questions, and decision rules. In general, analysis of the monitoring data will employ some combination of descriptive and inferential statistics and time-series analysis. Some common data analysis methods are described in detail in *Guidance for Data Quality Assessment* (QA/G-9) (USEPA 2000b); additional information may be found on the USEPA Quality System website (www.epa.gov/quality).

Finalize the decision rules
During the optimization, a decision is made on which of these approaches or what combination of approaches would best meet the monitoring DQOs. Once an optimized monitoring design has been completed, the data collection methods should be evaluated to ensure that they can be successfully implemented given the site conditions and within the applicable cost and budget constraints. Optimization continues with implementation of the Monitoring Plan. As monitoring data are being generated and evaluated, the Monitoring Plan should be revisited to see whether improvements, such as use of a different data collection method (e.g., a newer, cheaper, faster technology) or a revised sampling regime (e.g., a different sampling scheme) could be implemented without compromising the quality of previous collected data, while continuing to meet the monitoring DQOs.

Prepare Monitoring Quality Assurance Project Plan (QAPP)
The final aspect of developing the monitoring design is the preparation of a Monitoring QAPP. The following items should be included in this QAPP:
- an overview and general background of the site activity for which the Monitoring Plan has been developed
- a description of the monitoring objectives
- the monitoring hypotheses, questions, and the monitoring conceptual model
- the data needs and characteristics
- the data collection methods, including details such as sampling location, timing, and frequency
- the sampling equipment and procedures
- the data handling requirements
- the data analysis methods to be used

SMDP
The SMDP for Step 4 is the finalized Monitoring QAPP.

Step 5: Conduct monitoring analyses and characterize result

Conduct data collection and analysis
During Step 5, all data collection activities should strictly adhere to the study design identified in the Monitoring QAPP and be conducted at the times, locations, and frequencies specified by the DQOs.

Evaluate results according to the monitoring data quality objectives (DQOs) developed in Steps 1-4, and revise data collection and analysis methods as needed.
A major component of Step 5 is the evaluation of the data, as they are being collected, with regard to the DQOs. This evaluation assists the monitoring team to determine whether the data meet all requirements of the DQOs.

Thus, during the conduct of Step 5 the monitoring team should be continually evaluating and interpreting the data with regard to three basic questions:
- Do the data meet the DQOs?
- If yes, can the data collected to date support a decision rule? or
- If the data do not meet the DQOs, why not and what changes should be made so that the data meet the specified DQOs?

Characterize analytical results and evaluate relative to the decision rules

Evaluation of the data may show that the site activity is proceeding as expected, better than expected, or worse than expected. The specific outcome determines whether any modifications or adjustments to the site activity or to implementation of the Monitoring Plan may be appropriate. If the data indicate better than expected response (for example, if the soil concentrations are decreasing more rapidly than expected), then the monitoring team may consider revising the Monitoring QAPP as suggested by the data. In this case, it may be appropriate to revise not only the expected duration of the remedy and its associated monitoring program, but also aspects of the sampling regime related to sampling frequency. It may also be possible to reduce the sampling frequency and/or to proceed to a monitoring decision and overall site management decision sooner than had been originally planned, thereby reducing overall project costs. On the other hand, if the monitoring data indicate little or no change in soil concentration, or an increase in soil contaminant levels, then it would be appropriate to evaluate implementation of the plan, the site activity assumptions, and/or the remedy assumptions and the monitoring conceptual model. One might then identify possible revisions to the Monitoring QAPP, the remedy, or both.

SMDP

If at any point during the collection and analysis of monitoring data, the data are found to support the decision rule, then the site would proceed to Step 6. Alternately, if the analysis indicates that the data do not support the decision rule, then monitoring would continue as identified in the Monitoring Plan and QAPP

Step 6: Establish the management decision

If the monitoring results support the decision rule for successful conclusion of the site activity, conclude the site activity and monitoring.

In this case, the decision document should:

- identify the management decision and the underlying decision rules on which the decision is based;
- summarize the monitoring data and characterization;
- describe any uncertainties associated with the site activity, the Monitoring Plan, and the management decision;
- identify the monitoring team; and
- give the date of the decision.

If the monitoring results do not support the decision rule for site activity success, but trends indicate support of a decision rule, continue the site activity and monitoring.

In this case, the decision document should:

- identify the management decision and the underlying decision rules on which this decision is based;
- summarize the monitoring data, especially the analyses indicating the trend toward success of the activity;
- describe the uncertainties associated with the site activity, the Monitoring Plan, and the management decision;
- identify the monitoring team; and
- give the date and outline future actions and dates.

If the monitoring results do not support the decision rule and there is no trend towards support, conduct an analysis of the underlying factors and uncertainty, and revise site activity and/or the Monitoring Plan accordingly.

In this case, the decision document should:

- identify the management decision and the underlying decision rules on which the decision is based;
- summarize the monitoring data and characterization;
- describe the underlying factors and uncertainty analyses, and summarize the results, showing as clearly as possible why the decision rules were not met and why the site activity is considered to have not been successful;
- describe the actions needed to address the causative factors and uncertainties associated with the lack of activity success;
- identify the monitoring team; and
- give the date of the decision and the schedule for future actions.

SMDP

If the need for a completely new site activity is identified, then the development of the new activity should be conducted as required by the applicable regulatory process, and any applicable documentation requirements must be satisfied. Development of a new monitoring program may be necessary and would again follow the six-step process described above.

If only revisions to the existing site activity are necessary, these should be documented as required (e.g., an ROD, Record of Decision, addendum) by the applicable regulatory process under which the site activity is being conducted (e.g., CERCLA, Comprehensive Environmental Response, Compensation, and Liability Act, RCRA, Resource Conservation and Recovery Act) if such acts or similar acts are available in the country. Depending on the nature of the site activity revisions, a revised Monitoring QAPP ((see Step 4) may need to be prepared.

Documentation

Regardless of the management decision made in Step 6, documentation with respect to all aspects of the decision will be necessary. The specific nature of the decision document will depend on the decision made in Table 4.11 (USEPA, 2004).

Table 4.11
Management Decision Documentation

Management Decision	Management Decision Document Components	New or Revised Site Activity Decision Document Needed	New or Revised Monitoring QAPP Needed
Conclude site activity and monitoring	Management decision Monitoring decision rules Monitoring results Uncertainty description	No	No
Continue site activity	Management decision Monitoring decision rules Monitoring results, including trend analyses Uncertainty description	No	No
Revise site activity	Management decision Monitoring decision rules Monitoring results Causative factor analysis Uncertainty description Suggested activity revisions	Yes – revised	Yes – revised
Replace site activity	Management decision Monitoring decision rules Monitoring results Causative factor analysis Uncertainty description	Yes – new	Yes - new

Source: USEPA (2004) Table 6-1, p.6-5

4.9 TOOLS AND RESOURCE

CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
I. Contaminant(s) Characteristics	**A.** **Degree of hazard** • High concern contaminants – high concentration • High concern contaminants – low concentration • Medium concern contaminants – high concentration • Medium concern contaminants – low concentration • Low concentration contaminants	14 11 8 5 3	In determining the degree of hazard of a waste, it is recognized that a listed hazardous waste is generally of greater concern than a liquid or solid industrial waste. These are in turn of greater concern than other solid wastes. Municipal and organic wastes are considered medium concern contaminants due to their putrescible nature (production of methane and other landfill gasses). Household wastes may contain hazardous materials (e.g., batteries, medical wastes, paints, etc).	Determine the level of hazard according to the following table of typical contaminants and definition of high concentrations: **High Concern Contaminants** • Materials defined as dangerous goods in the Transport of Dangerous Goods Act and Regulations • Materials identified by Province as hazardous waste (pesticides, herbicides, paint sludge, acid and alkaline solutions, solvents, etc.) • Materials regulated by the Canadian Environmental Protection Act (e.g., PCBs) • Institutional waste (lab, schools, hospitals, etc.) • Pathological wastes and animal carcasses • Radioactive wastes **Medium Concern Contaminants** • Liquid waste not referred to in above, petroleum products, septic tank pumping, agricultural and chemical containers • Food processing wastes • Non-hazardous incinerator residues • Municipal solid (household) wastes • Organic and vegetable wastes • Mining residues **Low Concern Contaminants** • Industrial and commercial solid wastes, (e.g., construction materials such as wood, metal, hay, sand/silt piles, etc.) • Other nearly inert wastes (e.g., foundry sands) **High Concentration of Contaminants** • Contaminant concentrations in soil, groundwater or surface water exceed Canadian Environmental Quality Criteria for Contaminated Sites (>2x commercial/industrial level); or material that was deposited in highly concentrated form (e.g., >5000 ppm)	Transport of Dangerous Goods Act; Provincial/Territorial Hazardous Wastes lists; regulations under Canadian Environmental Protection Act; Canadian Environmental Quality Criteria for Contaminated sites; etc.
	B. **Contaminant Quantity (area/volume of site contamination)** • 10 ha, or 1000 m^3, or drums of liquid • 2 to 10 ha, or 100 to 1000 m^3 • <2 ha, or <100 m^3	 10 6 2	Little information is known about the quantity of wastes at abandoned sites in Canada. Therefore, waste quantity estimates may be interpreted from area or quantity information.	Measure or estimate the area or quantity of potential contamination. Note: Any number of drums abandoned or disposed is considered a high concern.	
	C. **Physical State of Contaminants** • Liquid/gas • Sludge • Solid	 9 7 3	Contaminants in liquid form are more mobile in the ground and water than solids. However, certain water-soluble solid wastes are more mobile than viscous liquids, and these should be evaluated on a caseby-case basis.	Determine the state of the contaminant when it was disposed or deposited.	
	Special Considerations	-6 to +6	(See 3.7.3 in text)	Technical judgment.	

SITE CLASSIFICATION WORKSHEET

(Instructions: Document site information, assign score, provide rationale behind score and indicate source of information in the spaces provided.)

I.	CONTAMINANT(S) CHARACTERISTICS	SCORE

A. **Degree of Hazard**
*List possible contaminants and
estimated concentrations*

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

B. **Contaminant Quantity**
*Estimated or measured area/
volume of contaminated zone:*

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

C. **Physical State of
Contaminant**

Does the site contain:
a) Predominantly liquids/gases
b) Primarily sludges
c) Primarily solids

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

Special Considerations
*Document any other important
contaminant characteristics
not addressed above:*

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

Site Identification: _____

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CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
II. Exposure Pathways	**A.** **Groundwater** 1. Known contamination at or beyond property boundary. • Groundwater significantly exceeds Canadian Drinking Water Guidelines (CDWG) by >2x or known contact of contaminants with groundwater • Between 1 and 2x CDWG or probable contact with groundwater • Meets Canadian Drinking Water Guidelines	11 6 0	The legislative basis for most jurisdictions is to prevent off-site migration of contamination	• Review chemical data and evaluate groundwater quality. If contamination at or beyond the property boundary exceeds Canadian Drinking Water Guidelines (CDWG) or applicable provincial/territorial guidelines or policies, or if contaminants are known to be in contact with groundwater, then evaluate the site as high	Canadian Water Quality Guidelines; Provincial Territorial Water Quality Guidelines or policies; Guidelines for Canadian Drinking Water Quality
	2. Potential for groundwater contamination a) Engineered subsurface containment • No containment • Partial containment • Full containment	 4 2 0	Well contained sites have minimal potential for pollution. Potential for pollution decreases with increasing contaminant.	Review the existing engineered systems and relate these structures to hydrogeology of the site and determine if full containment is achieved. Full containment is defined as an engineered system, monitored as being effective, which provides for the capture and treatment of contaminants. If there is no system, this factor is evaluated high. If there is less than full containment or if uncertain, then evaluate as medium. Typical engineered systems include leachate collection systems and low permeability liners.	
	b) Thickness of confirming layer over aquifer(s) of concern • 3m or less • 3 to 10 m • >10 m	 1.5 1 0	The thickness of a confining layer (e.g., clay, shale, etc.) between contaminants and any aquifers of concern will affect the attenuation of contaminants and hence the quantity and quality of contaminants reaching the aquifers.	Measure or estimate thickness of any confining layer (e.g., clay, shale, etc.) over all aquifers of concern from existing well records or from a general knowledge of local conditions. If possible, an estimate of the continuity of the confining layer should be made from borehole well record information. Note: an aquifer is defined as a geologic material that will yield groundwater in useable quantities.	Historical geologic maps, well records, government hydrogeologist or local consultants.
	c) Hydraulic conductivity of the confining layer • >10^{-4} cm/sec • 10^{-4} to 10^{-6} cm/sec • <10^{-6} cm/sec	 1.5 1 0.5	The rate at which contaminants migrate through the confining layer will affect attenuation and the contaminant loading to the aquifers.	Determine the nature of geologic materials and estimate hydraulic conductivity from published material (or use "Range of Values of Hydraulic Conductivity and Permeability" figure at end of Section 4.9). Clays, granite, shales should be scored low. Silts etc. should be scored medium. Sand, gravel, and limestone should be scored high.	Freeze and Cherry, 1979, and other groundwater texts.

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SITE CLASSIFICATION WORKSHEET – cont'd

II.	EXPOSURE PATHWAYS	SCORE

A.   Groundwater

1.   Known Groundwater Contamination
Document information on known groundwater contamination:
_____
_____
_____
_____

Scoring Rational & Information Source: _____   ❏

2a.   Engineered Subsurface Containment
Document engineered systems protecting groundwater:
_____
_____
_____
_____

Scoring Rational & Information Source: _____   ❏

2b.   Thickness of Confining Layer Over Aquifier(s) of Concern

Document local geological conditions:
_____
_____

Identify water-bearing zones used for water supply:
_____
_____

Scoring Rational & Information Source: _____   ❏

2c.   Hydraulic Conductivity of the Confining Layer
Estimate hydraulic conductivity of any confining layer:
_____
_____
_____

Scoring Rational & Information Source: _____   ❏

Site Identification: _____

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CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
II. Exposure pathways – cont'd	**A.2.** **(d) Annual Rainfall** • 1000 mm • 600 mm • 400 mm • 200 mm	1 0.6 0.4 0.2	The quantity of rainfall affects the quantity of leachate produced. Higher leachate quantities have a higher impact on the environment.	Refer to Environment Canada records for relevant areas. Use 30-year average rainfall for evaluation purposes. Divide rainfall by 1000 and round to the nearest tenth (e.g., 667mm = 0.7 score).	Hydrological Atlas of Canada (Fisheries and Environment Canada, 1978).
	(e) Hydraulic conductivity of aquifer(s) of concern • 10^{-2} cm/sec • 10^{-2} - 10^{-4} cm/sec • $<10^{-2}$ cm/sec	3 1.5 0.5	Aquifers with high hydraulic conductivity can transport contaminants at high velocity over great distances, e.g., solution limestones, highly fractured rocks or gravel deposits.	Determine the nature of geologic materials and estimate hydraulic conductivity of all aquifers of concern from published material (refer to "Range of Values of Hydraulic Conductivity and Permeability" figure at end of Appendix D).	Freeze and Cherry, 1979.
	Special Considerations	-4 to +4	(See 3.7.3 in text)	Technical judgment.	

SITE CLASSIFICATION WORKSHEET – cont'd

| II. | **EXPOSURE PATHWAYS (cont'd)** | **SCORE** |

A.   Groundwater (cont'd)

2.d   Annual Rainfall

Document rainfall data: _____

_____

_____

Scoring Rational & Information Source: _____ ❑

2.e   Hydraulic Conductivity of Aquifier(s) of Concern

Estimate conductivity of relevant aquifier(s): _____

_____

_____

Scoring Rational & Information Source: _____ ❑

3.   Special Considerations

Document any other important groundwater issues not addressed above: _____

_____

_____

Scoring Rational & Information Source: _____ ❑

Site Identification: _____

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USER'S GUIDE – cont'd

CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
II. Exposure Pathways (cond'd)	**B.** **Surface Water** 1.　　Observed or measured contamination of water/effluent discharged from site. • Known or strongly suspected to exceed Canadian Water Quality Guidelines (CWQG) by >2x • Known or strongly suspected to be between 1 – 2x CWQG • Meets Canadian Water Quality Guidelines	11 6 0	The legislative basis in all jurisdictions is not to contaminate surface water beyond established limits.	Collect all available information on quality of surface water near to site. Evaluate available data against Canadian Water Quality Guidelines (select appropriate guidelines based on local water use, e.g., recreational, irrigation, freshwater aquatic life, etc.) and relevant provincial/territorial water quality objectives.	CCME Canadian Water Quality Guidelines; Relevant provincial/territorial and federal legislation and regulations.
	2.　　Potential for surface water contamination a)　　Surface containment • No containment • Partial containment • Full containment	5 3 0.5	The level and type of engineered containment will affect the potential for contaminants to be released to surface water.	Review the existing engineered systems and relate these structures to site conditions and proximity to surface water, and determine if full containment is achieved; e.g., evaluate low if there is full containment such as capping, berms, dikes; evaluate medium if there is partial containment such as natural barriers, trees, ditches, sedimentation ponds; evaluate high if there are no intervening barriers between the site and nearby surface water	Site inspection reports, air photos, etc.
	b)　　Distance to perennial surface water • 0 to <100 m • 100 to 300 m • >300 m	3 2 0.5	The distance to surface water will affect the probability of contaminants reaching the watercourse. The Ontario Ministry of the Environment has established a classification for immediate impact zone at 50 m. For conservatism, this zone has been broadened to 100 m.	Review available mapping and survey data to determine distance to nearest surface water bodies.	
	c)　　Topography • Contaminants above ground level and slope is steep • Contaminants at or below ground level and slope is steep • Contaminants above ground level and slope is flat • Contaminants at or below ground level and slope is flat	1.5 1.2 0.8 0	Water can run off (and therefore potentially contaminate surface water) with greater ease from elevated sites on slopes.	Review engineering documents on the topography of the site and the slope of surrounding terrain. • steep slope ＝ >50% • flat slope ＝ <5% Note: Type of fill placement (e.g., trench, above ground, etc.)	

SITE CLASSIFICATION WORKSHEET – cont'd

II. **EXPOSURE PATHWAYS (cont'd)**   **SCORE**

B. **Surface Water**

   1. **Observed or Measured Contamination** _____
      Document information on surface water _____
      contamination: _____
      _____

      Scoring Rational & Information Source: _____ ❏

   2a. **Surface Containment** _____
      Review and document engineeredor _____
      natural systems protecting surface _____
      water: _____

      Scoring Rational & Information Source: _____ ❏

   2b. **Distance to Perennial Surface Water**

      Estimate distance from site to nearest _____
      stream or other water body: _____
      _____

      Scoring Rational & Information Source: _____ ❏

   2c. **Topography**
      Document terrain conditions: _____
      _____

      Document position of contaminants (are _____
      they above ground or buried?): _____
      _____

      Scoring Rational & Information Source: _____ ❏

Site Identification: _____

USER'S GUIDE – cont'd

CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
B. Exposure pathways (cont'd)	**B.2.** **(d) Run-off potential (see nomograph, end of Appendix D)** • >1000 mm rainfall and low permeability surface material • 500 to 1000 mm rainfall and moderately permeable surface material • <500 mm rainfall and highly permeable surface material **(e) Flood potential** • 1 in 2 years • 1 in 10 years • 1 in 50years	 1 0.6 0.2 0.5 0.3 0.1	Run-off transports contaminants into water bodies. Water run-off is a function of precipitation and the rate of infiltration (less permeable soils will allow greater run-off). The potential for large quantities and concentrations of contaminants to be released to surface water courses over a short period of time will be affected by the flood potential of a water course near the site.	Refer to Environment Canada precipication records for relevant areas. Use 30-year average precipitation for evaluation purposes. Determine factor score using "Run-Off Potential Nomograph" figure at end of Appendix D. Review published data such as flood plain mapping or flood potential (e.g., spring or mountain run-off) and Conservation Authority records to evaluate flood potential of nearby water courses both up and down gradient. Rate zero if site not in flood plain.	Hydrological Atlas of Canada (Fisheries and Environment Canada, 1978). Established flood plain guidelines/maps; provincial/territorial soil survey maps.
	Special Considerations	-4 to +4	(See 3.7.3 in text)	Technical judgment.	

SITE CLASSIFICATION WORKSHEET – cont'd

II.   **EXPOSURE PATHWAYS (cont'd)**   **SCORE**

C.   **Surface Water (cont'd)**

2.d. Run-off Potential
Document geological and rainfall
conditions:

_____

_____

_____

_____

Scoring Rational & Information Source: _____   ❑

2.e. Flood Potential
Estimate flood frequency of nearby
water courses or water bodies:

_____

_____

_____

_____

Scoring Rational & Information Source: _____   ❑

3.   Special Considerations
Document any other important surface
water conditions not addressed above:

_____

_____

_____

_____

Scoring Rational & Information Source: _____   ❑

Site Identification: _____

CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
II. Exposure Pathways (cont'd)	**C. Direct Contact** 1. Known contamination of media off-site • Known contamination of soil, sediment or air off-site due to contact with contaminated soil, dust, air, etc. (vector transported should also be considered). • Strongly suspected contamination of media off-site • No contamination of media off-site	11 6 0	Known or measured contamination off-site is an important consideration for determining impact of contaminants.	Record known or measured contamination of soil, sediment or air on or off-site. Note any presence of soil gas, such as methane, associated with site.	
	2. Potential for direct human and/or animal contact i) Airborne Emissions (gasses, vapours, dust, etc.) • Known or suspected airborne emissions impacting on neighbouring properties • Airborne emissions generally restricted to site • No airborne emissions	5 3 0	If air emissions are evident off-site, there is a great hazard for direct contamination of neighbouring biota and/or resources.	Review available site information to determine if there have been complaints off-site (due to vapours, gas, dust, etc.). Reports for these problems are not likely available for most abandoned sites. Review regulatory site inspection reports. If airborne emissions are known to be impacting neighbouring properties and possibly endangering the public, some immediate action (including characterization of emissions) should be initiated to curtail hazardous emissions or otherwise reduce or eliminate exposure.	Site inspection reports, etc.
	ii) Accessibility of Site (ability to contact materials) • Limited or no barriers to prevent site access; contaminants not covered • Moderate accessibility or intervening barriers; contaminants are covered • Controlled access or remote location and contaminants are covered	4 3 0	The greater the accessibility to a site and to contaminants, the greater the chance for contamination of human and animal life by direct contact.	Review location and engineering of the site and determine if there are intervening barriers between the site and humans or animals. A low rating should be assigned to a (covered) site surrounded by a locked chain link fence or in a remote location, whereas a high score should be assigned to a site that has no cover, fence, natural barriers or buffer.	
	iii) Hazardous soil gas migration • Contaminants are putrescible and soil permeability is high • Soil contaminants are putrescible but soil permeability is low and/or groundwater is <2 m from surface • No putrescible contaminants at the site	2 1 0	Methane gas migration has been known to cause explosions adjacent to abandoned landfills.	Consider presence of organic material on site, the depth to water table, soil hydraulic conductivity, vegetative stress, odours, etc.	
	Special Considerations	-4 to +4	(See 3.7.3 in text)	Technical judgment.	

SITE CLASSIFICATION WORKSHEET – cont'd

		SCORE

II. EXPOSURE PATHWAYS (cont'd)

C. Direct Contact

1. Known Contamination of off-site:
Document reports of off-site contamination due to contact with contaminated soil, dust, air, etc.:

_____
_____
_____
_____

Scoring Rational & Information Source: _____   ❑

2.a. Airborne Emissions
Document incidents or complaints about fumes, gases, dust, odours, etc.:

_____
_____
_____

Scoring Rational & Information Source: _____   ❑

2.b. Accessibility of Site
Review and document avenues of site access by humans and animals:

_____
_____
_____

Scoring Rational & Information Source: _____   ❑

2.c. Hazardous Soil Gas Migration
Review potential for hazardous soil gas production and migration from site:

_____
_____
_____

Scoring Rational & Information Source: _____   ❑

3. Special Considerations
Document any other conditions whereby humans/animals could contact contamination:

_____
_____
_____

Scoring Rational & Information Source: _____   ❑

Site Identification: _____

CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
III. Receptors	**A. Human and Animal Uses** i. Known adverse impact on humans or domestic animals as a result of the contaminated site • Known adverse effect on humans or domestic animals • Strongly suspected adverse effect on humans or domestic animals	18 15	Contamination from a site that causes a measurable impact on humans to a great concern.	Review and evaluate reports of impact(s) of site contamination (e.g., increased heavy metal levels measured in blood of nearby residents as a result of site contamination). Any site assigned 15 or more points for this factor should automatically be classified as Class 1. An adverse effect is considered to be any one or more of the following: i) impairment of the quality of the natural environment for any use that can be made of it, ii) injury or damage to property or to plant or animal life, iii) harm or material discomfort to any person, iv) impairment to the safety of any person, v) rendering any property or plant or animal life unfit for use by humans, vi) loss of enjoyment of normal use of property, and vii) interference with the normal conduct of business (from Ontario Environmental Protection Act, 1980)	
	2. Potential for impact on humans or animals a) Drinking water supply i) Known impact on drinking water supply Drinking water supply is known to be adversely affected as a result of site contamination • Known contamination of drinking water supply to levels above CDWG • Strongly suspected contamination of drinking water supply • Drinking water supply is known not to be contaminated ii) Potential for impact on drinking water supply ° Proximity to drinking water supply • 0 to <100 m • 100 to <300 m • 300 m to <1 km • 1 to 5 km ° "Availability" of alternate drinking water supply • Alternate drinking water supply is not available • Alternate drinking water supply would be difficult to obtain • Alternate drinking water supply available	 9 7 0 6 5 4 3 3 2 0.5	Water used for drinking should be protected against contamination from any site. The nearer a drinking water well is to a contaminant source, the greater the potential for contamination. Well water used for irrigation/agriculture purposes should also be included as it may be used for human consumption. This factor takes into account the availability of replacement water supplies, and is used in the technical sense as a factor to indicate the degree of urgency, not as a sociopolitical consideration.	Review available site data (inspection reports, assessment documentation) to determine if drinking water (groundwater, surface water, private, commercial or municipal supply) is known or suspected to be contaminated above Guidelines for Canadian Drinking Water Quality or applicable provincial/territorial guidelines or policies. If drinking water supply is known to be contaminated above these guidelines, some immediate action (e.g., provision of alternate drinking water supply) should be initiated to reduce or eliminate exposure. Review provincial/territorial base mapping or air photos and measure the distance to the nearest resident or drinking water supply. Judge whether the water is being used as a drinking water source. Commonly rural areas use groundwater for drinking purposes. For urban sites, contact the local Public Utilities Commission to determine water source and location. Determine availability of alternate drinking water supply or distance to alternate source.	Guidelines for Canadian Drinking Water Quality; other drinking water guidelines developed by recognized agencies (e.g., other Health and Welfare Canada guidelines, USEPA, etc.)

SITE CLASSIFICATION WORKSHEET – cont'd

III. **RECEPTORS**   SCORE
A. **Human and Animal Uses**
1. **Known Adverse Impact on Humans or Domestic Animals:** _____
   Record known or suspected adverse _____
   effects on humans or domestic animals: _____
   _____

   Scoring Rational & Information Source: _____ ❏

2.a.i. Known Contamination of Drinking Water Supply _____
   Record known or suspected incidents of _____
   contamination of drinking water: _____
   _____

   Scoring Rational & Information Source: _____ ❏

2.a.ii. °Distance to Nearest Drinking Water Supply(s) _____
   Identify nearest drinking water well and _____
   measure distance to site: _____
   _____

   Scoring Rational & Information Source: _____ ❏

2.a.ii. °°Availability of Alternate Drinking Water Supply _____
   Document availability of alternate _____
   sources of drinking water and ease of _____
   implementation: _____

   Scoring Rational & Information Source: _____ ❏

Site Identification: _____

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CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
III. Receptors (cont'd)	**A.2.** **b) Other Water Resources** i. Known impact on used water resource Water resource (used for recreational purposes, commercial food preparation, livestock watering, irrigation or other food chain uses) is known to be adversely affected as a result of site contamination • Water resource is known to be contaminated above CWQG • Water resource is strongly suspected to be contaminated above CWQG • Water resource is known not to be contaminated	 4 3 0	The water used for these purposes (groundwater or surface water) should be protected against contamination.	Review documentation for reported or suspected contamination of water used for recreation or food chain uses, and refer to Canadian Water Quality Guidelines or other relevant guidelines (select appropriate guidelines based on local water use) to determine if supply is considered contaminated.	CCME Canadian Water Quality Guidelines; provincial/territorial water quality guidelines and objectives, etc.
	ii. Potential for impact on water resources °Proximity to water resources used for activities listed above • 0 to <100 m • 100 to <300 m • 300 m to <1 km • 1 to 5 km	 2 1.5 1 0.5	The nearer a water resource is to a site, the greater the risk of contamination.	Determine distance from the site to the nearest recreational or food chain used water resource.	
	°Use of water resources – if multiple uses, give highest score (use following table)	0.2 - 2	Potential for impact due to use of water resource is related to the type and frequency of use. Human uses are of the highest concern.	Assess water uses adjacent to the site from maps and directories.	

Frequency of Use

Water Use	Frequent	Occasional
Recreational (swimming, fishing)	2	1
Commercial food preparation	1.5	0.8
Livestock watering	1	0.5
Irrigation	1	0.5
Other domestic or food chain uses	0.5	0.3
Not currently used but likely future use	0.5	0.2

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SITE CLASSIFICATION WORKSHEET – cont'd

III. RECEPTORS (cont'd)   **SCORE**
A. Human and Animal Uses (cont'd)
2.b.i. Known Impact on Used Water Resource: _____

Record information on water resource _____
that is or is potentially affected by site _____
contamination: _____

Scoring Rational & Information Source: _____ ❏

2.b.ii. ° Proximity of Water Resources to Site _____

Locate and measure nearest water _____
resource areas to site: _____

Scoring Rational & Information Source: _____ ❏

2.b.ii. °° Water Uses

Record uses of nearby water resources: _____

_____

_____

Scoring Rational & Information Source: _____ ❏

Site Identification: _____

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CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
III. Receptors (cont'd)	**A.2.** c) Direct Human Exposure i) Known contamination of land used by humans • Known contamination of land used for agricultural or residential/parkland/school purposes above AG or R/P EQC values • Known contamination of land used for commercial or industrial purposes above C/I EQC values • Land is known not to be contaminated	 5 3.5 0	Hazards associated with soil contamination are directly related to land use.	Review zoning and land use maps for land adjacent the site. Evaluate levels of soil contamination against Canadian Environmental Quality Criteria (EQC) for Contaminated Sites (AG = agricultural level; R/P = residential/parkland level; C/I = commercial/industrial level). If soil is known to be contaminated above these levels and possibly endangering public health, some immediate action (e.g., fencing the area, limiting public access, etc.) should be initiated to reduce or eliminate the exposure.	CCME Canadian Environmental Quality Criteria for Contaminated Sites.
	ii) Potential human exposure through land use • Use of land at and surrounding site (use following table; give highest score to worst case scenario) **Land Use** (current or future) Residential Agricultural Parkland/ School Commercial/ Industrial	0.5 - 5 **Distance from Site** **0 – 300m** **300m – 1km** **1 – 5km** 5 4.5 3 5 4 2.5 4 3 1.5 3 1 0.5	Hazards associated with soil contamination are directly related to land use and distance of the used land from the site. Residential and agricultural land uses are of highest concern because humans are situated at these locations for longer periods.	Review zoning and land use maps over the distances indicated. If the proposed future land use is more "sensitive" than the current land use, evaluate this factor assuming the proposed future use is in place (indicate in the worksheet that future land use is the consideration). Agricultural land use is defined as uses of land where the activities are related to the productive capability of the land or facility (e.g., greenhouse) and are agricultural in nature, or activities related to the feeding and housing of animals as livestock. Residential/Parkland land uses are defined as uses of land on which dwelling on a permanent, temporary, or seasonal basis is the activity (residential), as well as uses on which the activities are recreational in nature and require the natural or human designed capability of the land to sustain that activity (parkland). Commercial/industrial land uses are defined as land on which the activities are related to the buying, selling, or trading of merchandise or services (commercial), as well as land uses which are related to the production, manufacture, or storage of materials (industrial).	
	3. Special Considerations	-4 to +4	(See 3.7.3 in text)	Technical judgment.	

SITE CLASSIFICATION WORKSHEET – cont'd

III. RECEPTORS (cont'd)   **SCORE**

A. Human and Animal Uses (cont'd)

2.c.i. Known Contamination of Land used by Humans: _____

Record land use type (current or _____
proposed) and level of contamination for _____
land known to be contaminated due to _____
site:

Scoring Rational & Information Source: _____   ❏

2.c.ii. Land Use at and Adjacent to the Site _____

Document land uses (current and _____
proposed) for up to 5 km from the site: _____

N	E	S	W

0 - <300 m _____

300 m - <1 km _____

1 km – 5 km _____

Scoring Rational & Information Source: _____   ❏

3. Special Considerations _____

Document any other important human or _____
animal use information, including details _____
of air contamination if known: _____

Scoring Rational & Information Source: _____   ❏

Site Identification: _____

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CATEGORY	EVALUATION FACTOR	SCORING GUIDELINE	RATIONALE	METHOD OF EVALUATION	SOURCES OF INFORMATION
III. Receptors (cont'd)	**B. Environment** 1. Known adverse impact on a sensitive environment as a result of the contaminated site • Known adverse impact on sensitive environment • Evidence of stress on aquatic species or vegetative stress on trees, crops or plant life located on properties neighbouring the site • Strongly suspected adverse impact on sensitive environment	 16 14 12	The environment should be protected against site contamination. Evidence of impact(s) shows that protection is lacking.	Review records for evidence of vegetative stress or impairment of any nearby sensitive environments. A sensitive environment is defined as a sensitive aquatic environment, nature preserve, habitat for endangered species, sensitive forest reserves, national parks or forests, etc. An adverse effect is considered to be any one or more of the following: i) impairment of the quality of the natural environment for any use that can be made of it, ii) injury or damage to property or to plant or animal life, iii) harm or material discomfort to any person, iv) impairment of the safety of any person, v) rendering any property or plant or animal life unfit for use by humans, vi) loss of enjoyment of normal use of property, and vii) interference with the normal conduct of business (from Ontario Environmental Protection Act, 1980).	
	2. Potential for impact on sensitive environments a) Distance from site to nearest sensitive environment (e.g., sensitive aquatic environment, nature preserve, habitat for endangered species, sensitive forest reserves, national parks or forests, etc.) • 0 to <500 m • 500 m to <2 km • 2 to <5 km • 5 to 10 km	 10 6 2 0.5	It is considered that within approximately 1 km of the site there is immediate concern for contamination. Therefore, an environmentally sensitive area located within this area of the site will be subject to concern. It is also generally considered that any sensitive area located greater than 10 km from the site will not be impacted.	Review Conservation Authority mapping and literature. Also review Ministry of Natural Resources records and Federal Land Capability maps. Identify provincial/territorial and federal designated environmentally sensitive areas.	Relevant provincial/ territorial and federal maps of sensitive environments.
	b) Groundwater – distance to important or susceptible groundwater resource(s) • 0 to <500 m • 500 m to <2 km • 2 to <5 km • 5 to 10 km	 6 4 2 1	The closer a site is to a discharge or recharge area, the greater the potential for contamination of a groundwater or surface water resource.	Review groundwater contour maps, if available, and other available reports. Otherwise use established hydrogeologic principles.	Local groundwater maps, etc.
	3. Special Considerations	-4 to +4	(See 3.7.3 in text)	Technical judgment.	

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SITE CLASSIFICATION WORKSHEET – cont'd

		SCORE

III. RECEPTORS (cont'd)
B. Environment
1. Known Adverse Impact(s) on Sensitive Environment

Record known impact(s) on any sensitive biological environment at and/or around the site:

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

2.a. Distance from Site to Nearest Sensitive Environment

Document location, distance, type and details of any nearby sensitive environments or habitats:

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

2.b. Groundwater

Measure distance to major recharge or discharge area:

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

3. Special Considerations

Document any other important impacts on the environment not addressed above:

_____
_____
_____

Scoring Rational & Information Source: _____ ❑

Site Identification: _____

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RANGE OF VALUES OF HYDRAULIC CONDUCTIVITY
AND PERMEABILITY

HYDRAULIC CONDUCTIVITY (K) IN cm/s
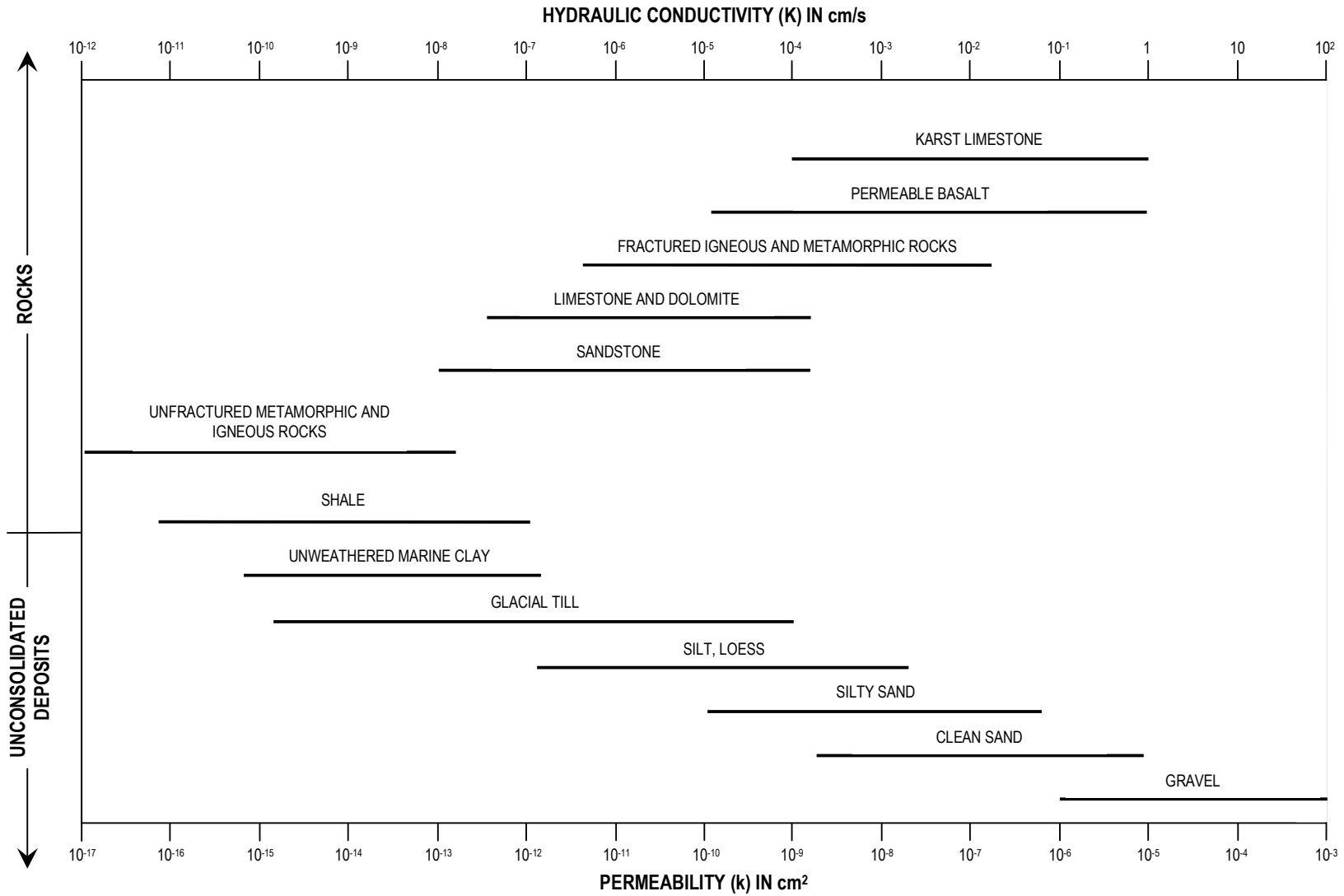
MODIFIED FROM FREEZE AND CHERRY, 1979 AND TODD, 1959

PERMEABILITY (k) IN cm²

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MODULE 5

COSTING AND FINANCING OF SITE REMEDIATION

This module provides guidance on the economic analysis of environmental policy issues related to sites contaminated by persistent organic pollutants.

Its step-by-step approach will help you to:

- calculate remediation costs and understand cost structures
- use cost-benefit analysis to evaluate remediation options, and
- select the most appropriate financing mechanism for the remediation.

5.1. INTRODUCTION AND OVERVIEW

As the pace of social and economic development accelerates in the developing countries, as will be evident in the rapid expansion of their production and consumption of chemicals, site remediation issues associated with persistent organic pollutants (POPs) will pose more significant challenges to human development and the environment. Besides, as developing countries become more concerned about cleaning up and managing POP-contaminated sites, the design and implementation of proactive site remediation policies will hinge on the identification, collation and analysis of information on the benefits, costs, and the financing mechanism of remediation options. Arguably, public and private evaluation of the costs and benefits of cleaning up, and the associated financing mechanism, will become an important policy input in the site remediation policy process.

This module is based on the premise that a carefully thought-out and implemented cost-benefit analysis and financing mechanism will greatly enhance the likelihood of success in the implementation of POP-contaminated site management and control policy. Also, such a framework will serve as a mechanism for organizing technical and socio-economic information. Even when a comprehensive cost-benefit analysis in developing countries, such as in Africa, confronts the problem of insufficient local data, the scoping exercise that available data allows, coupled with informed professional expertise and judgment ,should provide useful insights about more optimal management and elimination of these hazardous chemical pollutants.

Objectives and Scope

The main objectives of this module are threefold: (i) the identification and computation of the costs of POP-contaminated site remediation technology options, (ii) the economic and financial appraisal of the technology options, and (iii) the selection of a financing mechanism to support the site remediation options. Three main issues—cost and cost structures, cost-benefit analysis, and financing mechanism—define the scope of the presentation. A more detailed scope of the module includes the following:
- establish the costs and cost structures for remediating POP-contaminated sites
- present a framework for establishing the economic benefits and financial viability of remediation
- carry out socio-economic cost-benefit analysis and financial viability of remediation
- assess existing financial options/structure/arrangements for environmental management of polluted sites (cleanup and remediation)
- make recommendations on the appropriate roles for different stakeholders in ensuring sustainable chemical production and use
- identify the challenges/barriers to potential financing opportunities
- recommend removal strategies for these barriers
- develop a financing mechanism for sustainable remediation of contaminated sites

Overall, this module seeks to provide a rational economic basis for making the best possible choices about site remediation policies and technologies in the quest to eliminate or mitigate the adverse health and environmental consequences of POP contamination.

Of particular importance from an environmental policy perspective is the fact that the module provides a framework for determining whether the benefits of site remediation are worth the

costs from both the private and social perspectives. Ultimately, the socially optimal decision will be that which maximizes the net present value of remediation policy and POP strategy from a society's perspective, given the socio-economic conditions in a country.

How this Module is Structured

The rest of the module is structured as follows. Section 5.2 discusses the economic interpretation of the causal factors in the existence of POPs and the policy implications for the management of POP-contaminated sites. This is followed in section 3 by a discussion of the costs and cost structures associated with site remediation and the conceptual and empirical challenges of identifying and quantifying these costs. Section 5.4 outlines a methodological framework for evaluating site remediation based on cost-benefit analysis (CBA). This section deals with the identification and quantification of benefits and costs along with the challenges related to this approach. Section 5.5 examines the financing options and mechanism, and the emerging issues and challenges involved in funding cleanup efforts. The final section presents the conclusions.

5.2   THE ECONOMICS OF POPs

In this section, we review broadly some basic economic concepts and paradigms relevant to addressing the problems associated with the release, control, management and financing of POPs. The discussion presents an overview of the fundamental principles of the economics of the management and control of POPs and similar toxic chemical wastes. The subject matter is a complex and highly intriguing one, as it touches on important aspects of the symbiotic relationship between the activity of humans and their natural environment. The main objective of the exercise is to provide additional insight into making efficient policy choices for the purpose of reducing and eradicating of the negative effects of POPs on human civilization and the environment.

This section examines the following four broad questions:

- Why is there a POP problem?
- If POPs are hazardous, are there socially optimal levels for their production, use and disposal?
- What is the role of technology in the optimal management of POPs?
- What is the role of information failure in sub-optimal exposure to POPs?

Why is there a POP Problem?

Our point of departure is an economic explanation of the wide-ranging causal factors of POPs as a pollution problem (a negative environmental externality). Although many of them are seemingly non-economic in nature, they have strong economic roots. This is because economic activities of production, its intermediate processes and consumption contribute substantially to the negative environmental externalities that adversely impact environmental quality and human health. For the purpose of this discussion, a negative externality (spill-over) occurs when the action of an individual or firm imposes external costs upon another individual, or the society, for which no compensation is paid for the ensuing damage or disutility (Cropper and Oates, 1992; Folmer and Gabel, 2000).

The following basic considerations summarize the results of the analysis of the existence and undue exposure of the population to POPs, and the alternative policies to deal with the problem.

- Individuals and business enterprises, and the society as a whole, are continually faced with making choices among alternative uses of resources including environmental resources.
- How they, as decision-makers, evaluate the trade-offs between the alternative uses of resources, and their ultimate choices, help to illuminate the main causal factors in inefficient use of environmental resources that are evident in the POP pollution problem.
- Socially inefficient production, use and disposal of resources, including by-products of economic processes, will occur when the trade-offs do not adequately reflect the real economic values of those resources.
- Wrong calculations based on private, rather than social, valuations of resources are central to the emergence of excessive pollutants in the environment. Private costs diverge substantially from social costs.
- Valuation of the net benefit (benefits less costs) of alternative choices is at the core of the resource utilization decision-making problem.
- In each society there are a number of institutions that deal with the issue of valuation. The two major alternatives are the market mechanism and the government through administrative directives.
- Markets have the ability to filter human preferences to produce a set of prices that, in many cases, provide reasonably good information on the additional costs and benefits of producing and consuming the incremental unit of a scarce resource.
- When markets function properly, they produce more optimal prices for goods and services. However, getting and keeping them functioning properly remains a key policy challenge.
- The existence and persistence of POPs are manifestations of both market and government failures.
- Correcting these failures will produce a more desirable social and environmental outcome.
- Correcting the inefficient valuation through market-based incentive policy measures (such as the "polluter pays principle" discussed in Module 1, or marketable or transferable permits) has been at the core of environmental policy prescription by economists in recent times.

If POPs are Hazardous, Are There Socially Optimal Levels for their Production, Use and Disposal?

The answer to this question is in the affirmative, and the basic principle behind this position derives from conventional results that the optimal level of POP production, use and disposal occurs at the point where the marginal social cost of cleanup/abatement equals the marginal social benefit.[2]

More specifically, the following statements highlight the basic results:

---

[2] Figures 5.1 to 5.3 below provides graphical illustrations of this position. The optimal level of POPs occurs at the intersection of the marginal abatement cost function and the marginal social damage function. For more discussion see section 2.3 below.

- "Zero waste" and zero levels of POPs, though well intentioned, are difficult to achieve.
- Polluting chemical substances and waste cannot be completely eliminated without great cost either in terms of finding substitutes or lost future earned income.
- It is worthwhile to invest in reducing or eliminating toxic chemical products and their by-products, hazardous wastes, up to the point where the marginal cost equals the marginal benefit of taking remedial action.
- This involves internalizing the negative externalities pertaining to the production and consumption of chemicals associated with the release of POPs through a combination of regulatory standards and market-based incentive schemes.
- The socially desirable level of production of chemicals coincides with where the social marginal benefit equals the social marginal cost.
- Beyond this level of optimal pollution, the marginal polluter inflicts a cost on society that is not compensated for by the benefit that society gains from such economic activity. The desirable social outcome on which policy should be based involves internalizing the cost of such pollution.
- Internalizing costs implies that individuals and firms should bear the full cost of their behaviour as pertains to POPs.
- The polluter pays principle is the most notable economic principle in internalizing the externality cost of POPs.

The use of market principles in dealing with environmental issues and matters involving life has been a major source of controversy, especially among non-economists and environmentalists. An important caveat is that while markets generate a more efficient solution to the economic problem of resource allocation, they have not been efficient where health and ecological considerations are involved. Often, the real values of natural and environmental resources are poorly mediated by conventional market processes because the markets for these resources and the property rights associated with them, are poorly defined. Notwithstanding this caveat, the market valuation has provided, and still provides, useful insight into reaching socially efficient solutions to complex social and environmental problems.

What is the Role of Technology in the Optimal Management of POPs?

Figures 5.1 through 5.3 provide an overview of the economics of POP management. The following assumptions are essential in interpreting the graphs and understanding the conceptual framework for the role of information and technology in the optimal management of POPs and related environmental pollution problems.

- In all the diagrams, the horizontal axis measures the quantity of POP emissions.
- The vertical axis measures the value in monetary terms of the damages and abatement costs associated with the level of POPs.
- The society's valuation of the damage or avoided health risks from each additional level of exposure to POPs is represented by the marginal damage (MD) function.
    - The slope of the function will reflect whether each additional unit of exposure results in higher or lower damages. If each additional unit of exposure results in higher damages, the MD function will be upward sloping.

300

- When each additional exposure level is associated with higher damages, the slope of the MD function will be increasing, as is likely to be the case with POPs.
  - The MD function can also be interpreted to denote the marginal benefits of lower health and environmental risks when exposure to POPs changes.
- The society's valuation of the cost of abatement/remediation of each additional level of exposure to POPs is represented by the marginal abatement cost (MAC).
  - MAC reflects the relationship between the POP exposure level and the cost of abatement.
  - Abatement costs include:
    - costs of capital
    - labour
    - energy, and
    - and other inputs needed to abate the exposure to the level of pollution.
  - MAC slopes downward to reflect the fact that lower pollution exposure implies higher abatement costs for a given abatement technology.
  - MAC may also be interpreted as the marginal control costs of reducing the level of exposure to POPs.
- Optimal POPs level occurs where MAC and MD intersect.

In Figure 5.1 optimal POP exposure occurs at where MD_1 and MAC_1 intersect. Suppose the government has acquired more information about the adverse health risks of POPs or has become more aware of the problem. This implies that each unit of exposure is valued more in terms of the damages compared to the status quo. The impact of this assumption is shown in the leftward shift in the MD function from MD_1 to MD_2 as shown in Figure 5.1. The equilibrium shifts from pollution level e* to e_1. The shaded area illustrates the size of the environmental compliance cost when a new and lower level of pollution is enforced. The implication of this analysis is that lower exposure standard has a significant compliance cost to industry participants.

Figure 1: Cost and Benefit of Shift in Risk evaluation on POPs Pollution level

MD = Marginal Damage Function
MAC = Marginal Abatement Function
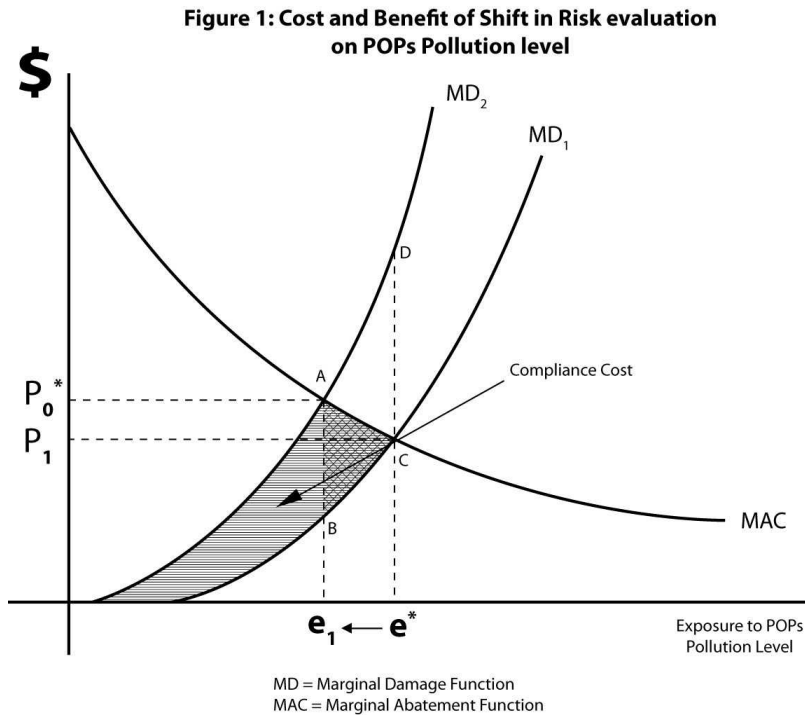
Figure 5.1
Cost and Benefit of Shift in Risk evaluation on POPs Pollution level

Figure 5.2 shows how technological changes can change the marginal abatement function. This is demonstrated by the leftward shift of the abatement cost function from MAC_1 to MAC_2. MAC_2.reflects the adoption of a new technology or best-practices technology that makes it feasible to achieve higher environmental standard e^*_1 instead of e^*_0 and at a lower social cost, P_1 compared to P_0. The role of technology in the economics of toxic chemical waste management is captured in the leftward shifts in MAC in Figures 5.2 and 5.3. The new equilibrium occurs at point B, which yields a lower exposure level to POPs, that is a shift from pollution level e^*_0 to e^*_1. At B compared to the original equilibrium A, the society achieves a higher environmental standard e^*_1 instead of e^*_0 and at a lower social cost, P_1 compared to P_0. The implication of this analysis is that technological progress can make significant impact on lowering exposure level and the net benefit to the society.

**Figure 2: Impact of Technological Innovation
that Lowers Abatement Costs**

MD = Marginal Damage Function
MAC = Marginal Abatement Function
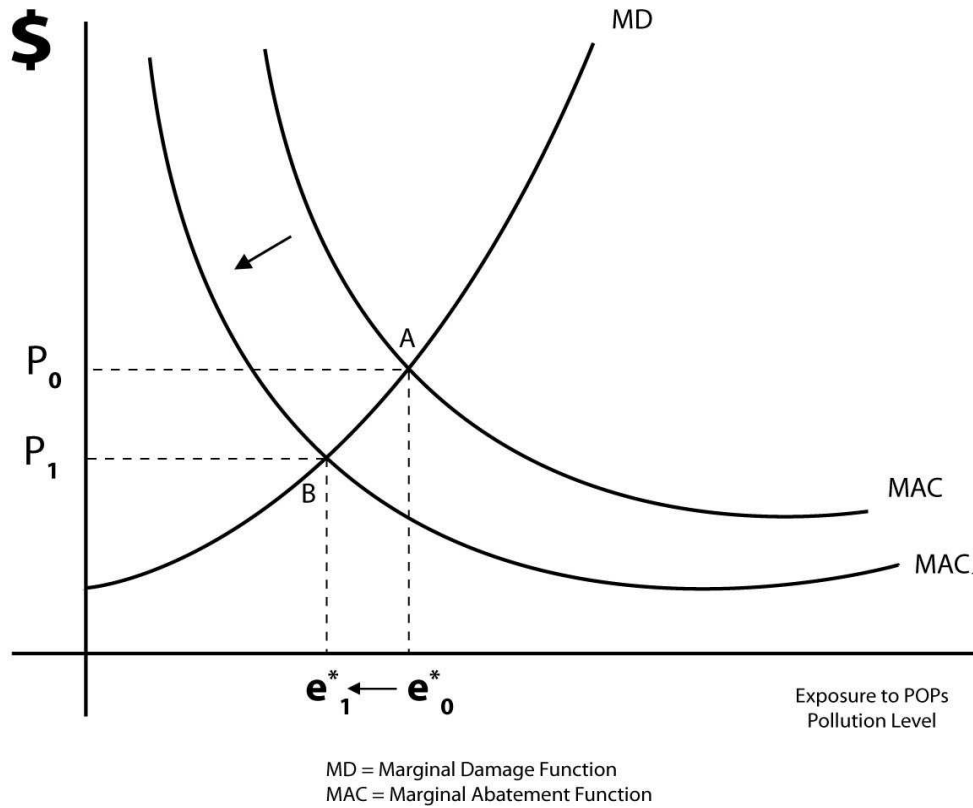
Figure 5.2
Impact of Technological Innovation that Lowers Abatement Costs

Figure 5.3 combines the effect of technological changes on abatement and a shift in the damage function valuation. The initial equilibrium occurs at F with the pollution level at e^*_0. The new equilibrium occurs at C. At C, the society achieves a higher environmental standard e_1 instead of e^*_0 and at a lower social cost, P_1 compared to P_0, compared to the original equilibrium, F. The striking result of this analysis is that technological progress can sufficiently lower the marginal abatement cost (from MAC_1 to MAC_2) to more than compensate for the higher valuation of each unit of exposure valued more in terms of the damages compared to the status quo. The prediction of the model is that society can achieve a lower pollution level at a lower cost to society. This is a form of the double dividend gain in environmental economics.
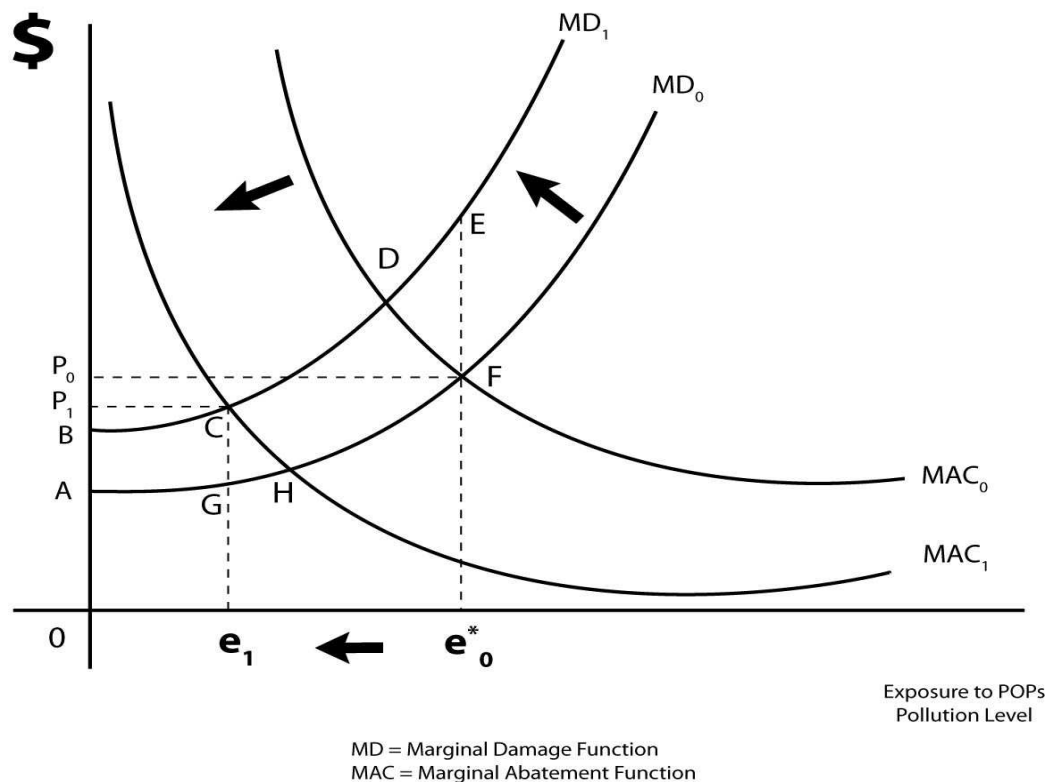
Figure 5.3
Impact of Shift in Valuation Risk and Technological Innovation on POPs Pollution Level

What is the Role of Information Failure in Sub-optimal Exposure to POPs?

The problem of POPs is interpreted in economics as arising from market failure, that is the failure of markets to function properly and provide reasonably good information on the additional costs and benefits of producing and consuming the incremental unit of a scarce resource, more so in markets for environmental and natural resources. The three main factors explaining market failure are:

- externalities
- market power, and
- information asymmetry.

Our focus in this section is on the role of information failure in the excessive exposure to POPs. Notably, information failure and government-induced economic distortions often combine to exacerbate the problem of environmental pollution.

Human exposure to POPs is due in part to market failure associated with imperfect information. When consumers make their choices under such conditions, they are faced with imperfect and incomplete information about the risks they face. This is often compounded by government failure evident in ineffective and inadequate regulatory standards and

enforcement. It is not surprising that many people in developing countries expose themselves to avoidable health hazards associated with polluted or chemically contaminated sites. People often live or work near chemically contaminated sites, despite their adverse morbidity and mortality effects, for a variety of reasons, among which ignorance of and/or inadequate information on the health risks are among the most important. Where land use zoning guided by good public health policy is poorly implemented, the likelihood that people, especially in low-income households, may work or live close to such sites is high.

Usually, the general public does not know the degree of risks (illness and death) posed by these chemical pollutants. The problem is exacerbated by the significant lag between environmental exposure and its health consequences, which may be several years or even decades. Consequently, people often tend to grossly undervalue the risks. Extensive dissemination of public information on the degree of risk to populations predisposed to locating near such sites would significantly reduce avoidable human exposure to hazardous chemicals and related risks. A socially optimal level of risk taking by individuals and business enterprises in low-income developing countries requires more information dissemination about such risks than in developed countries. The role of public information in ameliorating the information failure is indisputable.

The private and social cost of locating human settlements near POP-contaminated sites is considerable if such sites are not cleaned up. The dilemma in most developing countries with limited financial resources is about how clean contaminated sites should be after the remediation process. Despite the degree of exposure risks from a technical point of view, the degree of financial constraints may determine how clean the contaminated sites would be, partial or total.

Other factors in sub-optimal exposure to POPs

There are additional factors that account for the sub-optimal exposure of the population to POPs:
- High transactions costs, especially in developing countries, make it difficult for those adversely affected by toxic waste to use legal or other means to cause polluters to internalize the costs of the damages they cause by cleaning up the contaminated sites.
- The illegal dumping of toxic wastes is exacerbated by   poorly or undefined property rights to public landfills and free rider behaviour of producers of toxic wastes as producer of consumer goods and the public good nature of landfills.

Economic principles state that where property rights are undefined or poorly defined, or where remediating policies are poorly enforced or implemented, or where an institutional framework does not exist or is weak, or where there is a lack of or inadequate information about such adverse outcomes, as is the case with POPs in low-income developing countries, undesirable exposure of the population to toxic chemical substances will persist.

The design and implementation of good environmental policy in developing countries is more challenging than in the developed countries because of greater uncertainty and incomplete information on environmental issues. Underestimation and/or overestimation of environmental costs and benefits are more pressing in these countries, thereby necessitating more sensitivity analysis before drawing strong conclusions from such analysis. Also, past and current policies, and economic and social conditions, have exacerbated the problem of environmental degradation, of which POP site contamination is a key element. Citizens in

affected areas should receive information, which is a public good, as well as education, from their governments, who are best placed to provide this information directly, or to support the advocacy work of non-governmental organizations (NGOs) in this area.

The design of an incentive scheme that will induce individuals and firms, as producers and consumers, to engage in socially desirable behaviour that will yield socially desirable health and environmental outcomes is of utmost importance.

Economic Valuation of the Environment: Some Emerging Issues

Economic evaluation of risk management measures for POPs is an essential element of such sound environmental and development policy. Setting stricter standards may not be the most socially desirable remediation option available. Creating incentives that achieve the same goal at lower social cost may be more desirable. Ultimately, the socially optimal decision will be that which maximizes the present value of remediation policy and POP strategy from the society's perspective given the domestic socio-economic conditions.

A central theme in environmental economics and a source of controversy among environmentalists and scientists is economic valuation of environmental resources and assets. A natural resource and environmental accounting system has become a useful tool to incorporate non-economic factors in environmental policy analysis. Greening the national accounts by modifying them to include the depletion of natural resources and the environment has become increasingly popular in several countries (Ahmad et al., 1989; Reppetto et al., 1989).

An intriguing question concerns the use of the money metric to value environmental resources such as air, land, and surface and sub-surface waters. Notably, these environmental resources have provided the sink for the various pollution types arising from economic processes that underpin human development. However, overuse of natural and environmental resources manifested in serious environmental degradation problems, of which climate change is currently the most topical, has generated, and continues to generate, much debate.

Many natural and environmental resources have the characteristics of a public good. A public good is a good that once provided for an individual, it is not practicable to prevent others in the society from enjoying it. For example, if an individual or firm decides to clean up a POP-contaminated site, anybody living near the neighbourhood will benefit from the emerging rise in property values, and the lower risks to human health and damage to the environment, due to the cleanup. Air, water, and national security (military and police) are other examples of public good that are non-excludable and non-rivalrous. Economic principles suggest that the task of the government in such situations is either to be the provider of the public good or to provide the institutional framework and policy incentives to correct the market failure. However, to accomplish this task, the government should have an idea of how much value members of the society put on these environmental assets/resources.

Economic valuation of the environment: indirect and direct approaches

Imputing an economic value to the benefits or avoided health risks or other damages to individuals and firms near a POP-contaminated site is an essential input in making hard choices in an environment where resources are scarce. Notably, people directly or indirectly

put value on clean or polluted air, water and land through the decisions they make as to where they live, work or play. Such economic valuation are expressed explicitly or implicitly through the price they pay, or are willing to pay, or forgo, to live in less or more polluted areas of a city, a state or a country. Economic valuation also occurs when individuals make the choice of working in a more or less hazardous work environment and related pay structure, and where to recreate. The willingness to pay is considered a good reflection of the price of a good to an individual. While there are a number of important measurement issues that challenge social cost-benefit analysis of environmental issues such as POP site problems, the usefulness of this methodology in the design of sound environmental policy concerning POPs and other toxic chemical waste problems cannot be overstated. The scope of this study precludes any detailed discussion on this issue.[3]

There are two main approaches (Chilchinsky, 1997) that have been used to value the benefits and costs of associated with reversing or mitigating environmental pollution such as POPs. These are generically labelled as the indirect and direct valuation techniques or methods.

The indirect techniques, which use observable prices of market goods and services to value environmental goods and services for which no markets exist, consists of several methods including the following:

- the hedonic price model, which is based on property value differential or loss or gain in property value due to existence of an environmental problem, or on wage or income earning differential or value of income forgone
- the travel cost method

The direct technique, also called the Stated Preference Approach, is based on using survey methods, such as detailed questionnaires, to reveal the preferences and valuation of environmental goods and services of individuals. This approach consists of two major methods :

- contingent valuation:
- conjoint analysis

Valuing environmental risks to human life

Another significant debate in environmental policy concerns how to value environmental risks to human health. In circumstances where environmental pollution poses significant risks to human health in terms of higher morbidity and mortality, the convention is to use the concept of "value of life saved" in a statistical sense (Jones-Lee, 1982; Dardis, 1990; Johansson, 1993; Schelling, 1989; Mrozek et al., 2002). Valuing environmental risks to human health is an important consideration in environmental policy targeted at cleaning up chemical- and nuclear-contaminated sites. The United States Environmental Protection Agency (USEPA) has led the pioneering work on this issue, which is usually framed in terms of the benefit or value of life saved by reducing the mortality rate, for example, from two deaths to one in 100,000 people, as a result of improvement in the environment or reduction in exposure to the chemical pollutant (Mrozek and Taylor, 2002). Section 4 of this module adopts a similar methodology, based on the World Health Organization's (WHO) disability-adjusted life years (DALY) concept (WHO, 2008). This concept has been recently used by

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[3] For more and in-depth discussion on this and other issues in this section see Kahn, 1995; Folmer and Gabel, 2000.

the World Bank in a POPs study in Southeast Asia.[4] While the scope of this module precludes further discussion on this issue, the controversy associated with the appropriateness of valuing human life remains a subject of much debate (Jones-Lee, 1982).

5.3   COSTS AND COST STRUCTURE

This section outlines a general framework for the costs of POP-contaminated site remediation, which can then be entered into the financial and social viability analysis in Section 4. We begin the discussion by constructing the cost function for POP-contaminated site remediation based in part on a conceptual model (see Figure 5.4) that links POP-contaminated sources with receptors through the three exposure pathways/media: land, water (surface and underground) and air.
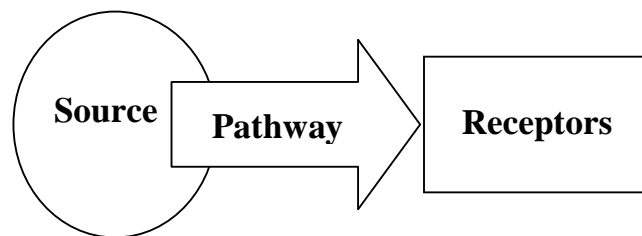
Figure 5.4
The Link between POP Contamination Sources and Receptors

Using this conceptual framework we can state the general form of the POP abatement cost function. Denote C as the total cost function for POP-contaminated site remediation.

The total cost function C is dependent on two group of factors, which are denoted by X and Y in Equation 1.

C = f(X, Y)   (Equation 1)

- X represents the conventional factor input vector consisting of capital, labour, energy, materials, transport, treatment and disposal of chemical wastes and substances.
- Y is a vector of characteristics that includes, among other factors, the following:
    - degree of remediation
    - contaminant characteristics
    - type of exposure control remediation technology
    - exposure pathways
    - accessibility of contaminated site to populated areas
    - size of contaminated areas,
    - receptor characteristics
        - socio-economic characteristics of the population
        - other receptor characteristics
    - costs including monitoring and enforcement costs

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[4] See www.popstoolkit.com.

Figure 5.5 presents a general framework used in this module for identifying and measuring the different categories of costs of contaminated site remediation options. It also shows the relationship between cost categories and the factors that affect them.
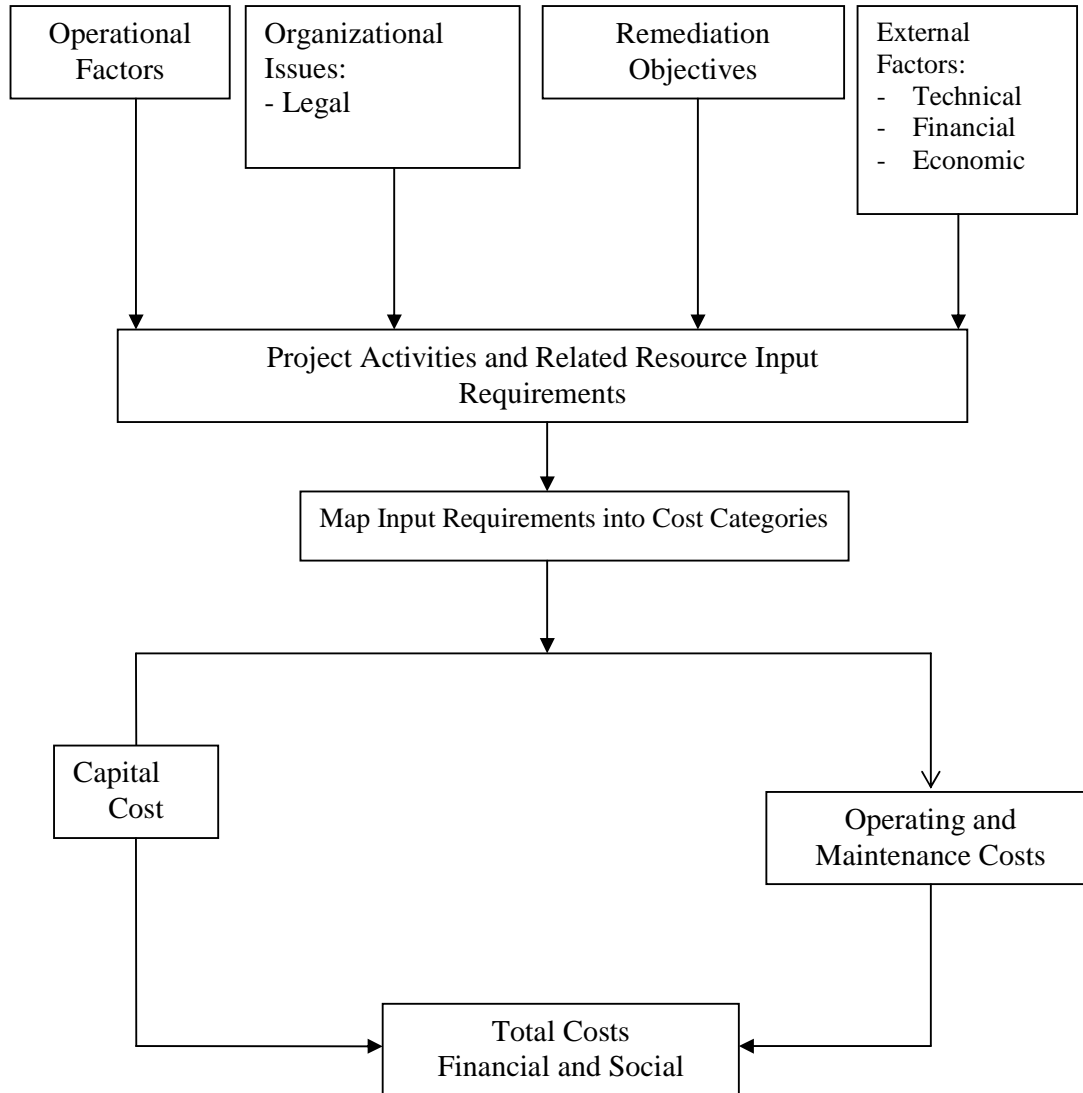
Figure 5.5
A General Framework for Cost Calculation

Typology of Costs

The three main categories of costs are as follows:

- capital and equipment cost used in the remediation process
- labour costs used in the remediation process:
    - skilled

- unskilled
- management
- other input costs used in the remediation process:
  - energy
  - material input e.g., chemicals and other supplies
  - transport
  - disposal
  - monitoring and control

Cost can also be classified broadly into the following:
- Private costs: These are financial costs incurred by an individual or a firm.
- Social costs: These costs represent the value lost to society, or the economy, of the goods and services that should have been produced but were given up to produce a certain good or service. In essence, they represent the total burden imposed on the society from an economic action. They reflect the society's opportunity cost of using a resource in an activity rather than its next best alternative. They equal financial cost plus the cost of internalizing the external cost imposed on other individuals or firms in the society.
- Explicit and implicit costs:
  - Explicit costs are costs for which explicit monetary disbursement is made, such as the cost of inputs.
  - Implicit costs are costs for which no explicit monetary disbursement is made, such as reduced (lost) output due to compliance with stricter environmental regulations.
- Direct and indirect costs:
  - Direct costs are costs that arise directly from disbursement on inputs in compliance with, say, stricter environmental regulation.
  - Indirect costs are costs due to changes in the prices of goods and services in the industry due to, say, stricter environmental regulations, impact of productivity decline or tight skilled labour market conditions.
- Fixed and variable costs
  - Fixed costs are costs that do not vary with output in the short run e.g., capital cost. Some operating and maintenance costs are also fixed.
  - Variable costs are costs that vary with output.

Basic Steps in Cost Estimation

There are basic six steps involved in the calculation of the cost structure for site remediation and related matters:

Step 1:   Identify clearly the remediation objectives that will affect the project.

Step 2:   Identify all operational and organizational factors, activities and actions that will reduce or avert exposure or the likelihood of human exposure to POP-contaminated sites with the following three stages of remediation duly recognized:
- pre-treatment /pre-remediation
- during-treatment remediation
- post-treatment remediation

Organizational operational factors include:
- legal policy
- workforce availability
- skill composition
- employee safety
- financial market conditions
- labour market conditions

Step 3: Identify the activities that would be carried out including monitoring and control of these activities. These activities are based on the operational and organizational factors that impact the site remediation project.

Step 4: Map the activities with resource requirement and cost categories, taking into consideration the three stages in Step 2. At this point, costs are highly disaggregated based on the mapping of activities and resource requirements into monetary valuation.

Step 5 Aggregate the cost structure into two main groups:
- capital cost, including set-up and other infrastructure costs
- operating and maintenance costs

Step 6: Identify the domestic and foreign components of inputs and costs, and value appropriately.

Other factors that will also enter the calculation of the cost structure include the following:
- size of the contaminated areas
- accessibility of site to human and animal habitations
- land use – residential, industrial, agricultural, others
- population distribution close to the contaminated site – high, medium or low density
- rural or urban area
- efficiency of the cleanup operation
- administrative costs of monitoring and enforcement
- preventive cost for cleanup workers
- exposure limit.
- degree of cleanup
- characteristics of the contaminants
- degree of the hazard
- location
- exposure pathways
  - land
  - water (ground and surface water)
  - air
- geography and geology
- receptor characteristics
  - land use – residential, commercial, industrial, agricultural, parks etc.
  - direct human exposure – land use

In addition, the cost structure will depend on how the remediation is carried out:
- onsite
- offsite
- permanent – complete removal of POPs
- partial – short term, medium term.
- to alleviate immediate or short-run risks.

Monetizing the resource inputs associated with the main activities involved in site remediation yields the financial costs of cleaning up such sites as formalized in Equation 1 above. These estimates will provide an empirical basis for analyzing alternative site remediation policies from a cost perspective. Cost estimation requires consistent valuation concepts for all the activities in the project alternatives; however, these costs must reflect their opportunity rather than sunk costs.

Table 5.1 presents a schema of a cost structure, which is based on alternative remediation technologies, from a financial perspective. (Tor further information on the selection of site remediation technologies, see Module 4.)

Challenges to Cost Estimation

There are a range of methodological challenges to the estimation of costs:
- identification of the correct measure of costs and their classification to avoid underestimation or overestimation
- changes in critical cost parameters such as exchange rate, inflation, energy costs, labour costs and interest rates
- whether to adopt a partial equilibrium or general equilibrium framework of analysis
- whether to adopt a static or dynamic framework of analysis
- the scope of the cleanup and site remediation
- the time horizon for the analysis
- the choice of the discount rate
- technological and scientific progress
- uncertainty
- policy changes

Table 5.1

Financial Costs of Remediation Technologies

	Combustion			Non Combustion								
	Incineration		Thermal Desorption	Super Critical Extraction	Phytore-mediation	Bio-bremediation	GPCR	Solvent Extraction	Vitrifi-cation	Pyrolysis	MCD	Sanitary land filling
In/Ex situ On Site/Off site Efficient Estimated cost (US$/m³)*	Ex On site 99.99% 140-360	Ex Off site 99.99% N/A	Ex/In On site 93-99.8% 350-450/ 350-700	Ex On site 99.99% 122-154* Partial cost	In On Site N/A 147-626	In/Ex On Site 60-80% 55-360	Ex On site 99.99% 500-630	Ex On site 95-99% 125-400	In/Ex On site 99.9% 500-8000	Ex On site 99.99% 375-500	Ex On site 70-91% N/A	Ex Off Site N/A 150
Pre-treatment Cost Labour Cost Monitoring Cost Power/fuel Cost Equipment Cost Installation/Decommissioning Cost Operational & Maintenance Cost Chemical (or equivalent) Cost Disposal Cost Transportation Cost Water Cost Patent Cost Post-Treatment Cost Sub-total												

Source: Li (2010) Module 4 of this POPs Toolkit

5.4 FINANCIAL VIABILITY AND SOCIAL COST BENEFIT ANALYSIS

The synergy between science, technology and economics in informing public decisions has been most vivid in environmental policy decision-making. Environmental policies often involve multiple objectives, which may conflict with one another. When resource constraints exist, the decision-maker must find a way to explicitly set priorities among competing alternatives/objectives; one such method is to use a quantitative evaluation system. In addressing complex environmental problems such as POP site remediation, policy-makers and the public clearly need guidance in selecting remediation technology options. They need to weigh the relative importance of the different options with the objective of maximizing net social benefit of such remediation policy. In the policy debate on POP management, cost-benefit analysis is a useful mechanism for organizing and interpreting the technical information surrounding contaminated sites (see Module 4). This methodology is especially well suited to the task of informing the decision-maker and the public about the trade-offs involved in site remediation as well as the underlying uncertainty surrounding the issue.

The basic principle behind cost-benefit analysis for POP-contaminated site remediation is to determine whether the benefit to society from such a policy action is worth the cost. The methodology uses a common metric to determine whether the project is worth being executed given that there are limited resources available to meet the social and economic needs of the population. Benefits and costs from the society's viewpoint are compared over a predefined time horizon. The expenditure on site remediation would be justified if the net present value of the project is positive.

In determining financial and economic viability we must answer the following questions:
- How much remediation should be done given that there are health risks associated with different level of cleanups?
- What is the size of the population living near the waste site?
- What is the risk of sickness (morbidity) or death (mortality) due to exposure to contaminated sites?
- What is the implication of best available technology in a country characterized by low income and high poverty incidence, fiscal constraints and declining economic fortunes?
- What should be the criteria for choosing one remediation technology over another for a given site?
- How do we value benefits and costs of remediation of hazardous chemical substances, such as POPs, when they have the characteristics of "public goods"?

The trade-off between costs and benefits is central to efficient and effective policy decision-making. Hard choices involve the tradeoffs, and cost-benefit analysis provides such trade-offs.

Figure 5.6 provides the framework adopted for carrying out financial viability and social cost-benefit analysis of contaminated site remediation. The financial costs are private costs often based on market prices. However, social costs differ markedly from private costs. When private costs are adjusted appropriately to reflect society's preferences they become social cost estimates. Social project benefits also differ from private benefits that accrue to individuals or enterprises who are only concerned with direct project revenues from contaminated site remediation. Social benefits are more encompassing. They can be classified into three categories:

- human health improvements evident in reductions in mortality and morbidity risks
- improvements to the environment
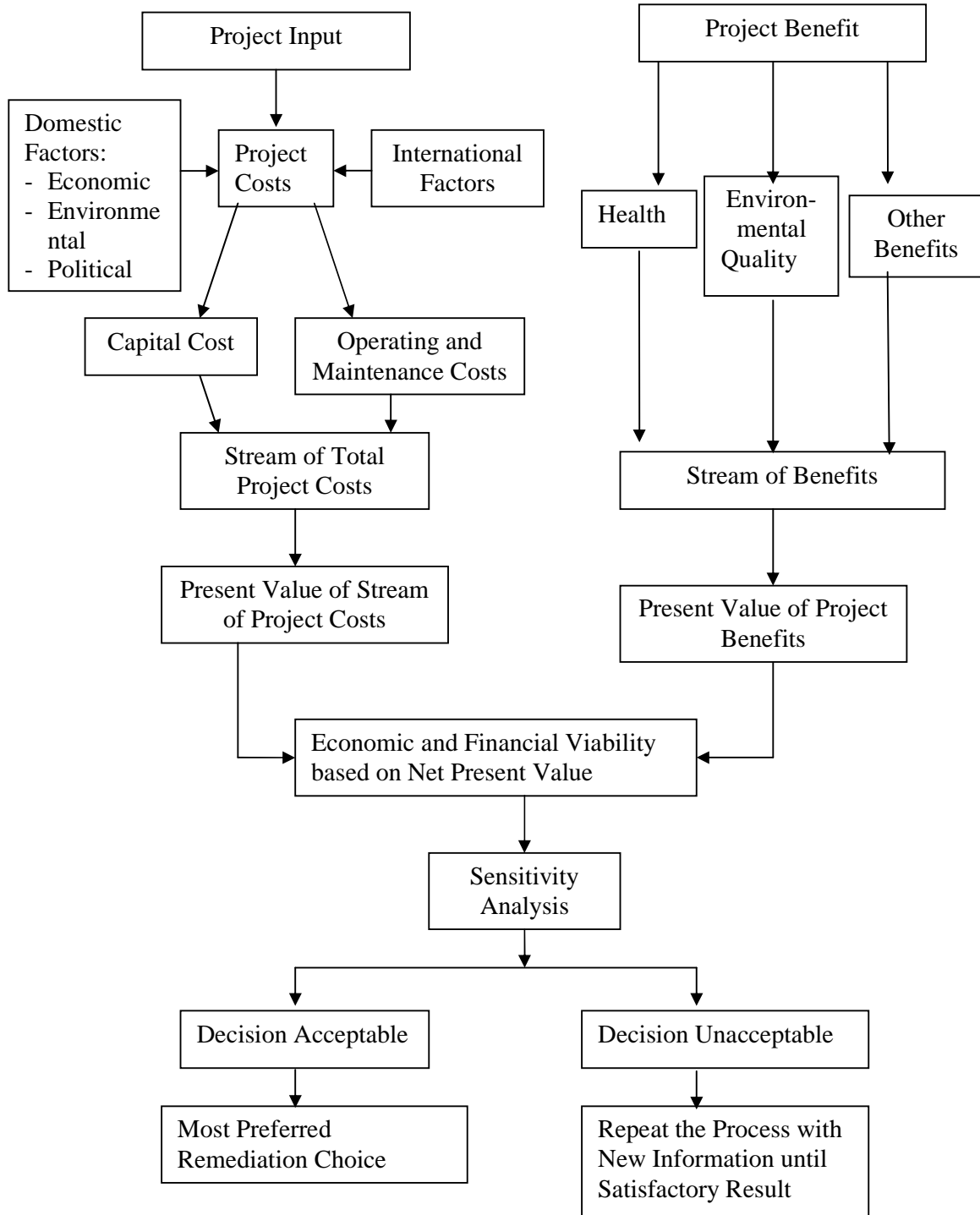- other benefits

Figure 5.6
A General Framework for Cost-Benefit Analysis

Financial Viability

Financial viability analysis is an important exercise for an enterprise interested in site remediation for profit motives, and involves the following activities:
- identification and quantification of costs of alternative contaminated site remediation technologies
- identification of the alternative uses to which the site can be put (e.g., land development for residential or commercial, industrial or agricultural uses)
- calculation of project revenues over a given time horizon e.g., 20 to 25 years
- choice of the cost of capital (interest rate) to use as the discount rate
- comparison of the discounted project costs and revenues
- choice of the remediation technology that yields the highest net present value of site remediation

Social Cost-Benefit Analysis

Figures 5.6 and 5.7 provide additional perspectives on social cost-benefit analysis of POP-contaminated site remediation. In Figure 5.7 we see a more general equilibrium framework for looking at the issue where site remediation benefits both households and business enterprises. The benefits are an improvement in the well-being of households through higher income from higher economic growth fuelled by market expansion and reduced health risks through site remediation. These benefits will include valuation of the reduction in health risks and environmental damage. The size of population affected directly and indirectly will impact the scale of the benefit. Options with lower costs would be preferred to options with higher costs. Based on cost-benefit analysis, the remediation technology option that meets the risk level and yields the highest net benefits is selected.
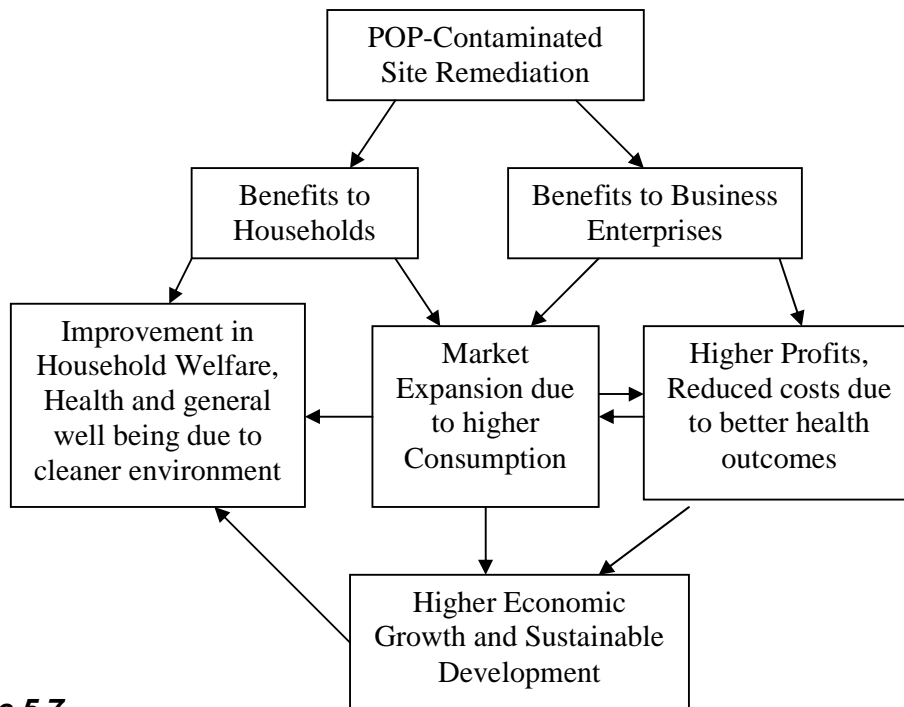
Figure 5.7
A General Framework for Understanding the Role of Contaminated Site Remediation

A Step-by-step Approach to Cost-Benefit Analysis

There are six basic steps in financial viability and social cost-benefit analysis, as shown in Figure 5.8.

Step 1:   Specify clearly the objectives of the POP-contaminated site remediation project/program.

Step 2:   Identify and categorize cleanup technologies and strategies according to their performance.

Step 3:   Determine the relevant flow of inputs and outputs including:
- the physical specification of the project, and
- the inputs required for setup and operation.

This process involves predictions of future trend of inputs and output (future growth patterns and technical changes,) and possibly consumer preferences.

Step 4:   Assign values to input and output flows using a metric that translates all the input and output flows into a common measure and money. Benefits and costs are measured in monetary units. The calculations could be supplemented by valuation of the intangibles.

Step 5:   Calculate the present values of costs and benefits in order to calculate the net present value (NPV) using an appropriate discount factor. Determine for each technology whether the NPV is positive or negative.

Step 6:   Choose the preferred policy by comparing the NPVs. Carry out sensitivity analysis by recalculating the NPV based on changes in key prices and costs, and the discount rate.

The difference between financial and economic viability are in two respects. Financial viability is based on financial values while economic viability use social costs and social benefits as the basis of computing net present values. Usually the discount rate for social analysis is lower than for financial analysis because the society discounts the future much less than an individual or a private firm.
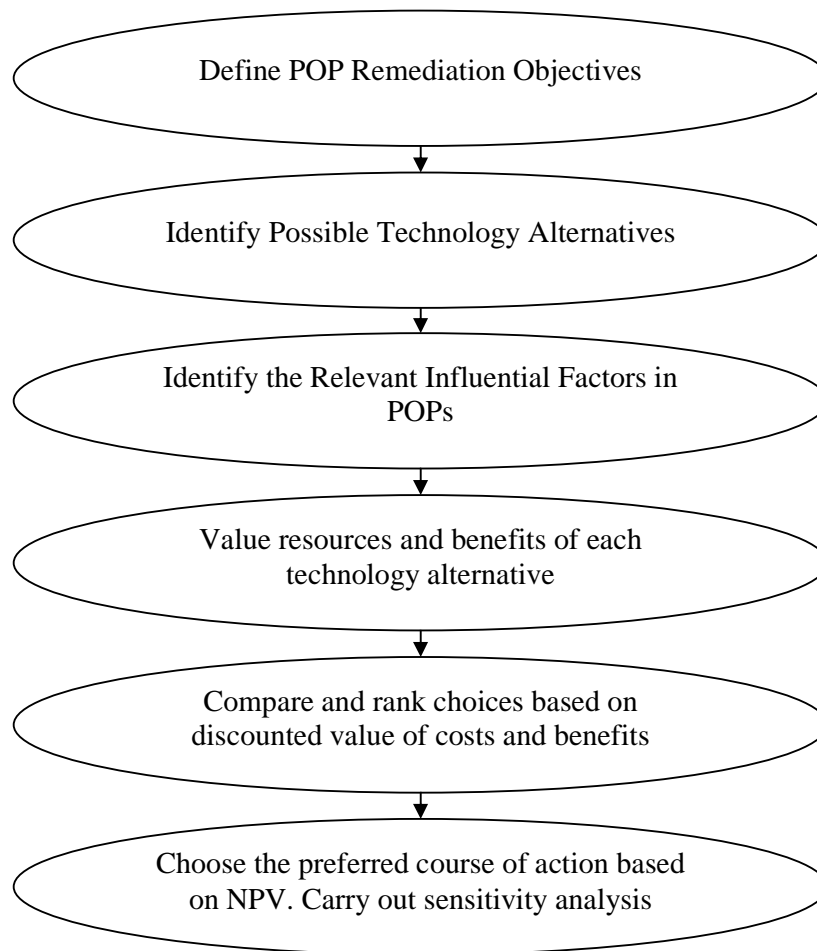
Figure 5.8:
Six Basic Steps in CBA for POP-Contaminated Site Remediation

Table 5.2 provides an overview of financial viability for site remediation with 12 alternative technologies to choose from. The information in the table is generated by carrying out the following steps:

- Determine the project objective.
- Determine the time horizon for the project.
- Determine the discount rate/opportunity cost of capital.
- For each technology (each row), calculate the costs of contaminated site remediation.
- Generate the annual cost flows for each technology.
- Generate the project revenues based on, for example, investment in residential or commercial, or industrial properties, or farmland or recreational park. The revenue flows will be similar for all the technology options.
- Calculate the annual values of the project revenues for each technology (each row of the table).
- Calculate the discounted or present values of net benefit (revenue) for each technology (each row of the table)
- Find the row with the highest net present value: it is the chosen remediation technology.

Table 5.2
Net Present Value OF Remediation Technologies

Technology Type	Time Period							
								T= Terminal Period
(abbreviations)	0	1	2	3	4	…….	……	
	NB*0	NB1	NB2	NB3	NB4			NBT
Incineration Off-site (IOF)	NBIOF0	NBIOF1	NBIOF2	NBIOF3	NBIOF4			NBIOFT
Incineration On-site (IOS)	NBON0	NBON1	NBON2	NBON3	NBON4			NBONT
Thermal Desorption(TD)	NBTD0	NBTD1	NBTD2	NBTD3	NBTD4	..	…..	NBTDT
Super Critical Extraction (SC)	NBSC0	NBS1	NBS2	NBS3	NBS4			NBST
Phytoremediation (PY)	NBPY0	NBPY1	NBPY2	NBPY3	NBPY4			NBPYT
Bioremediation (IO)	NBIO0	NBIO1	NBIO2	NBIO3	NBIO4			NBIOT
GPCR (GP)	NBGP0	NBGP1	NBGP2	NBGP3	NBGP4			NBGPT
Solvent Extraction (SE)	NBSE0	NBSE1	NBSE2	NBSE3	NBSE4			NBSET
Vitrification (V)	NBV0	NBV1	NBV2	NBV3	NBV4			NBVT
Pyrolysis (PYR)	NBPYR0	NBPYR1	NBPRY2	NBPRY3	NBPRY4			NBPRYT
MCD (MCD)	NBMCD0	NBMCD1	NBMCD2	NBMCD3	NBMCD4			NBMCDT
Sanitary Landfilling (SLF)	NBSLF0	NBSLF1	NBSLF2	NBSLF3	NBSLF4			NBSLFT

*NB is the present value of net benefit for each year.

$$NPV = NB0 + \frac{NB1}{(1+r)} + \frac{NB2}{(1+r)^2} + ... + \frac{NBT}{(1+r)^T}$$

Where r is the discount rate and T is the terminal period.

Dealing with Uncertainties and Risks: Sensitivity Analysis

Uncertainties and risks are pervasive in environmental policy issues such as POPs. One useful way to address this issue in this module is to answer the *What if?* question. For example, we may want to find out how robust the analysis is to discount rate or exchange rate? Also, what is unique about each of the sites considered, but not captured by the CBA technique? It is virtually impossible to develop an evaluation approach that is both concise enough to be useful, and extensive enough that exceptions are never needed. Both technical and political judgments are required in deciding which variables to include and exclude. Sensitivity analysis has become an invaluable aspect of both financial viability and social benefit analysis.

Using DALY to Calculate Social Benefit

In circumstances where environmental pollution such as POPs poses significant risks to human health in terms of higher morbidity and mortality, economic convention suggests the use of the concept of "value of life saved" in a statistical sense. Disability-Adjusted Life Years (DALY) is used to calculate benefits from reduction in adverse human health effects due to site remediation. Annual project benefits are defined in terms of reduction in mortality and morbidity. DALY, an index compiled by the WHO for its member countries, represents

the potential years of life lost due to premature death as well as the equivalent years of "healthy" life lost due to poor health or disability (WHO, 2008).[4]

DALY combines, in a single parameter, the time lived with a disability, and the time lost due to premature mortality. For our purpose, these are likely consequences of exposure to POP contamination. For application to contaminated site analysis, the national parameter has to be localized. An appropriate transformation is the following:

- DALY $_{site}$ = (DALY $_{national}$ x Potentially Exposed Population at site)/100,000. (The 100,000 in the denominator is to indicate that DALY is per 100,000 populations.)

Finally, the economic value of DALY must be calculated using the Value of a Statistical Life (VSL) (Mrozek & Taylor, 2002). At the end of the calculation, the benefits of the site remediation are quantified in terms of mitigation of adverse health impacts and as a percentage reduction in the total DALYs at the site.

Challenges to Benefit Estimation

There are many methodological and empirical challenges to the estimation of benefits:

- identification of the correct measure of benefits to avoid underestimation or overestimation
- changes in critical cost parameters such as exchange rate, inflation, energy costs, labour costs and interest rates
- whether to adopt a partial equilibrium or general equilibrium framework of analysis
- whether to adopt a static or dynamic framework of analysis
- the scope of the cleanup and site remediation
- the time horizon for the analysis
- the choice of the discount rate
- uncertainty
- technological and scientific progress

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[4] The reader can download the WHO's DALY values for its members at the WHO website at
   http://www.who.int/healthinfo/global_burden_disease/en/

5.5.   FINANCING MECHANISM

The question of how to finance POP site remediation has bearing on the management of the problem. When both the financing and other relevant scientific and management aspects of POP reduction or elimination are examined in a holistic framework, the greater is the likelihood of success of such a program. A poorly designed financing mechanism could flounder or stall a program, notwithstanding how good or well-thought out the other processes may be. This is true for both developing and developed countries where both private and public sources of funding the cleanup would have to be found.

In this section we shall discuss the financing mechanism for the remediation of a POP-contaminated site, and identify the specific policies and support instruments for effective funding (see Figure 5.9 for an illustration of various financing options).

Financing options can be divided into three broad categories according to source:
- public resources
  - domestic
  - international
- private resources
  - domestic
  - international
- public-private partnerships
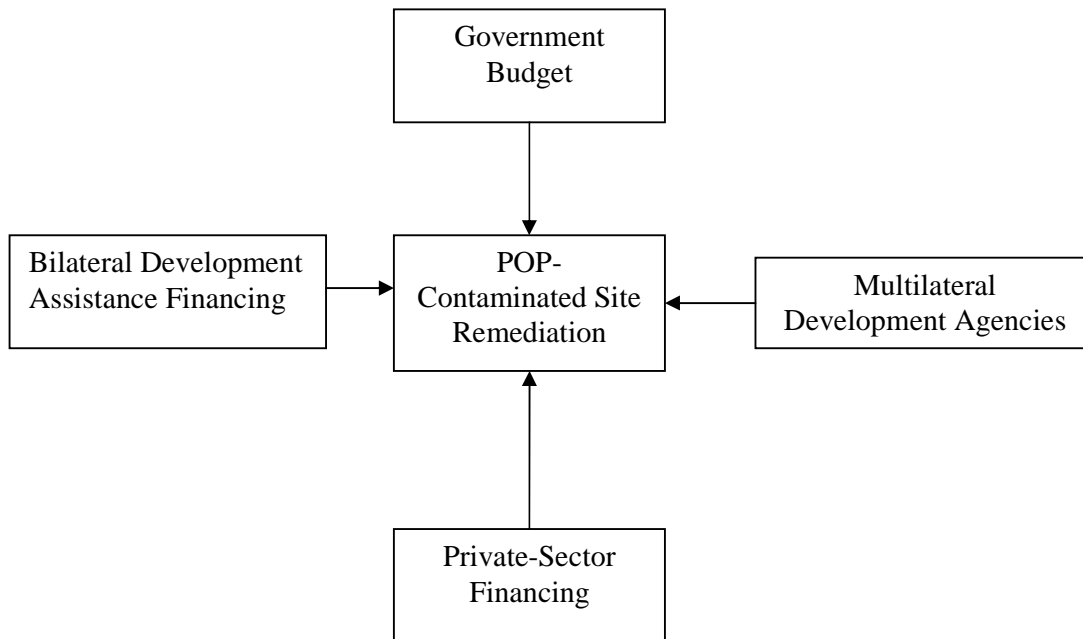
Figure 5.9
POP Site Remediation Financing Options

Public Sources of Financing

There are three potential public sources available for financing the remediation of POP-contaminated sites:
- the government of the remediating country
- bilateral developing agencies
- multilateral developing agencies

The government of the remediating country

This financing option could either be through general or environmental taxes, subsidies, or grants. Some of the sources include:
- funds generated through the polluter pays principle, which seeks to force firms to internalize pollution costs;
- taxes on all firms in the chemical and petroleum sectors;
- taxes imposed only on firms that produce or use toxic chemical substances in their production processes;
- a special levy on imported chemicals and petroleum products;
- corporate environmental income taxes imposed on all firms in the economy;
- corporate environmental income taxes imposed on all firms that produce or use toxic chemical substances in their production processes;
- an environmental tax on the consumption of POPs and similar toxic chemical substances; and
- ecological funds (such as in Nigeria), which are appropriate sources of finance since the environmental degradation associated with POPs and similar toxic chemical substances have both short- and long-term adverse effects on human health and livelihood.

The institutional setup in each country, and its political economy, will determine which options, out of the menu of public sources, are politically feasible. An analysis of the incidence of the various taxes, along with their administrative and compliance costs, will help determine which is the least welfare reducing.

Bilateral development agencies

The second public source is funding from foreign governments and their bilateral aid agencies, either through direct foreign aid or as part of counterpart funding.

Financing from multilateral development agencies

The third source is funding from multilateral agencies, including global funds such as the UN's Global Environmental Fund. Notably, co-financing has become part and parcel of global funds for environmental restoration.

Private Sources of Financing

Private enterprises source funding for site remediation are from their internal or external resources. There are a number of potential funding sources.

- Corporate social responsibility requires firms, especially large ones, to undertake cleanup voluntarily. This, coupled with Corporate Environmental Responsibility, provides another basis for site remediation.
- In the quest to support a cleaner society and support government remediation efforts, sector operators in the chemical and petroleum industry could set up a contributory financing scheme to support current and future cleanup activities anchored on self-regulation.
- All tiers of government could provide such firms with economic incentives to establish a fund to support significant site remediation effort voluntarily.
- Threats, or stricter monitoring and enforcement of more stringent liability laws, may induce firms in the chemical industry to support remediation.
- Based on a country's risk financing framework, domestic financial markets may want to create new financial instruments to finance such ventures through contingent credit facility.
- Domestic insurance markets may also be a source of funding.
- As development accelerates, underpinned by rapid economic growth, especially in developing countries, private entrepreneurs may be motivated by profits to invest in site remediation for residential, commercial, agricultural and/or industrial purposes.

Public-Private Financing

The public-private partnership option, which has increasingly become attractive for the provision of infrastructure services in many developing countries, is also feasible for financing the remediation of POP-contaminated sites. It would mean that the remediation decision-making process would benefit from greater private-sector efficiency in managing resources. This could help guarantee a more efficient remediation operation including selecting the most cost-efficient remediation technologies.

Joint financing would strengthen the relationships and coalitions between governments and private stakeholders with respect to environmental governance. It would also give private firms a greater stake in remediation projects, and more involvement in the implementation of policies that support sustainable development.

Removing Barriers to Financing

There are a number of barriers to mobilizing resources to finance the remediation of POP-contaminated sites including:
- the political will of the government
- domestic economic and social conditions
- global financial and economic conditions
- the extent of pressure from domestic and international stakeholders for a government to be proactive in environmental matters that impact the health of the population, and
- the financial position of bilateral and multilateral development agencies including the UN.

Good governance, improved national and international economic conditions, and the exertion of unrelenting pressure by major stakeholders on governments and their aid agencies are essential for removing the barriers identified above. Most important is the political will of a

government to proactively establish adequate financial support for an institutional infrastructure and framework to support sound environmental policy, including for POPs and other emerging hazardous chemical products and waste. The performance record of many developing countries with respect to the clean development mechanism suggests that although funds may be available, the capacity to use them may be limited..

5.6   THE FUTURE FOR THE DEVELOPING COUNTRIES

As developing countries fully join the chemical race, as would become apparent in their production and consumption of chemicals, remediation issues associated with POP-contaminated sites will pose more serious challenges to human and animal health, and the environment. Consequently, governments and other stakeholders should be engaged in designing proactive policies to mitigate and/or eliminate the risks posed by toxic chemical substances in the production and consumption processes. The prevention of the inappropriate disposal of POPs is more than just an important environmental policy issue. It should also be seen as part of the desired goal of sustainable human development. Developing countries, however, are faced with several challenges:

- finding smart and efficient solutions to the remediation of POP-contaminated sites that are driven by the development and widespread promotion of cleaner, safer, efficient and affordable technologies
- designing and implementing management and control policies helpful in reducing or eliminating the dependence and exposure to hazardous chemicals such as POPs in economic processes[5]
- finding the financial and human resources to meet the requirements for efficient management and disposal of POPs and similar toxic chemical substances given that many of them are struggling to meet the Millennium Development Goals, a struggle that has been exacerbated by the significant financial and economic problems that have arisen from the dramatic collapse in world financial markets and the ripple effects on the world economy
- taking a long-term planning and sustainable budgeting view for the elimination and mitigation of POPs, given that the budgetary challenge may mar or support the credibility and effectiveness of the planning effort for past, current and prospective contaminated site remediation activities.

Despite the current serious economic and social problems facing most developing countries and economies in transition, it can be argued that a proactive and robust chemical policy to address POPs and similar toxic chemical problems is not only an investment in the future health of the people but also in a cleaner and safer environment for them, and in overall sustainable development. The trans-boundary nature of the problem of hazardous waste, and the challenges faced by developing countries with weak environmental institutions, point to the need for more global support for their contaminated site remediation initiatives. Since POPs are chemicals that move freely around the world with no borders or frontiers, their

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[5] These processes include on-the job exposure in production activity in agriculture, manufacturing and informal sector activities in developing countries. Also, a variety of economic goods contain toxic chemical substances to which consumers and producers may be exposed to without being fully informed about their health risks. In addition, there is the generation and disposal of toxic waste as by-products of the production and consumption process.

correction, and its financing, must be a mandatory, jointly shared local and international responsibility.

Transparency is important to the assessment and remediation of POP-contaminated sites, not only as a means of combating corruption, but also as a aid in preventing the concealment of politically unpalatable information and to raise awareness of the risks and dangers of POPs. Transparency and public participation go hand in hand, with strong public participation strengthening the position of authorities as well as keeping the objectives clear and understandable to all. Public participation anchored on widely publicized information on the health and environmental hazards of chemical pollutants, such as POPs, will provide an opportunity for better public understanding and support for the significant investment that is required for effective contaminated site remediation.

Clearly, the business-as-usual approach has become outdated health-wise, both politically and environmentally. A paradigm shift, driven by policies anchored in the society's perception of the costs and benefits of alternative site remediation technological options, is *sine qua non* for intergenerational equity. As a final point, while the protection of human health and the environment from the adverse consequences of economic activity (production and consumption) associated with hazardous chemical substances remains a major policy challenge, the role of economics in reaching the correct policy decisions will remain invaluable.

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Module 5   Costing and Financing Site Remediation

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