The existence of contaminated sites may result in the release of chemical contaminants into various environmental compartments. Any contaminant released into the environment will be controlled by a complex set of processes (such as intermedia transfers, degradation, and biological uptake). In fact, many chemical contaminants are persistent in the environment and undergo complex interactions in more than one environmental medium. Contaminated sites should therefore be carefully and thoroughly investigated so that risks to potentially exposed populations can be determined with a reasonably high degree of accuracy. Typically, different levels of effort in the investigation will generally be required for different contaminated site problems. Ultimately, the application of a well-designed diagnostic assessment plan to a contaminated site problem will ensure that appropriate and cost-effective corrective measures are identified and implemented for the site.

2.1 INVESTIGATION OF POTENTIALLY CONTAMINATED SITES

Site investigations consist of the planned and managed sequence of activities carried out to determine the nature and distribution of contaminants at potentially contaminated sites. The activities involved usually are comprised of the identification of the principle hazards, the design of sampling and analysis programs, the collection and analysis of environmental samples, and the reporting of laboratory results for further evaluation (BSI, 1988).

The most important primary sources of contaminant release to the various environmental media are usually associated with constituents in soils at contaminated sites. The contaminated soils can subsequently impact other environmental matrices. The impacted media, having once served as “sinks”, may eventually become secondary sources of contaminant releases into other environmental compartments. Table 2.1 summarizes the important sources and “sinks” or receiving media associated with typical contaminated site problems. In general, all relevant sources and impacted media should be thoroughly evaluated as part of the site investigation efforts.

In order to get the most out of a site investigation, it must be conducted in a systematic manner. Systematic methods help focus the purpose, the required level of detail, and the several topics of interest — such as physical site conditions, likely
Table 2.1 Potential Release Mechanisms from Various Contaminant Sources and Target Media

<table>
<thead>
<tr>
<th>Primary contaminant source</th>
<th>Typical release</th>
<th>Primary receiving media</th>
<th>Potential release mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface impoundments</td>
<td>Loading/unloading activities</td>
<td>Air, Soils and sediments</td>
<td>Surface water, Groundwater</td>
</tr>
<tr>
<td></td>
<td>Overtopping dikes and surface runoff</td>
<td>Groundwater</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seepage and infiltration/percolation</td>
<td>Subsurface gas (in soil pores, vents, and cracks migrating through soil)</td>
<td></td>
</tr>
<tr>
<td>Waste management units</td>
<td>Migration of releases outside unit’s runoff collection and containment system</td>
<td>Air, Soils and sediments</td>
<td>Surface water, Groundwater</td>
</tr>
<tr>
<td>(e.g., landfill, land treatment unit, and waste pile)</td>
<td>Migration of releases outside the containment area from loading and unloading operations</td>
<td>Subsurface gas (in soil pores, vents, and cracks migrating through soil)</td>
<td>Volatilization</td>
</tr>
<tr>
<td>Waste management zones</td>
<td>Migration of runoff outside containment area</td>
<td>Air, Soils and sediments</td>
<td>Surface water, Groundwater</td>
</tr>
<tr>
<td>(e.g., container storage area and storage tanks)</td>
<td>Loading/unloading area spills</td>
<td>Subsurface gas (in soil pores, vents, and cracks migrating through soil)</td>
<td>Fugitive dust generation</td>
</tr>
<tr>
<td></td>
<td>Leaking drums, leaks through tank shells, and leakage from cracked or corroded tanks</td>
<td>Subsurface gas (in soil pores, vents, and cracks migrating through soil)</td>
<td>Volatilization</td>
</tr>
<tr>
<td></td>
<td>Releases from overflows</td>
<td>Subsurface gas (in soil pores, vents, and cracks migrating through soil)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leakage from coupling/uncoupling operations</td>
<td>Subsurface gas (in soil pores, vents, and cracks migrating through soil)</td>
<td></td>
</tr>
<tr>
<td>Waste treatment plants/facilities</td>
<td>Effluent discharge to surface water and groundwater resources</td>
<td>Surface water (by dissolution, dispersion, transport, etc.)</td>
<td>Sediments from adsorbed chemicals, Groundwater</td>
</tr>
<tr>
<td>Incinerators</td>
<td>Routine releases from waste handling/preparation activities</td>
<td>Air, Foliage (from particulate deposition and atmospheric fallout)</td>
<td>Soils (from particulate deposition and atmospheric washout)</td>
</tr>
<tr>
<td></td>
<td>Leakage due to mechanical failure</td>
<td>Soils (from particulate deposition and atmospheric washout)</td>
<td>Surface water (from particulate deposition and atmospheric washout)</td>
</tr>
<tr>
<td></td>
<td>Stack emissions</td>
<td>Surface water (from particulate deposition and atmospheric washout)</td>
<td>Groundwater (by dissolution, dispersion, etc.)</td>
</tr>
<tr>
<td>Injection wells</td>
<td>Leakage from waste handling operations at the well head</td>
<td>Groundwater (by dissolution, diffusion, dispersion, etc.)</td>
<td>Surface water (from groundwater recharge)</td>
</tr>
</tbody>
</table>

BOX 2.1
Tasks and Elements of a Site Investigation Program

Problem Definition and Preparatory Evaluation:
- Define objectives (including the level of detail and topics of interest)
- Collect and analyze existing information (i.e., review available background information, previous reports, etc.)
- Conduct visual inspection (i.e., field reconnaissance surveys)
- Construct preliminary conceptual model of site

Sampling Design:
- Identify information required to refine conceptual model of the site
- Identify constraints and limitations (e.g., access, presence of services, financial limitations)
- Define sampling and interpretation strategy
- Determine exploratory techniques and testing program

Implementation of Sampling and Analysis Plans:
- Conduct exploratory work on site (e.g., exploratory borings, test pits, geophysical surveys, etc.)
- Perform in situ testing
- Carry out sampling activities
- Compile record of investigation logs, photographs, and sample details
- Perform laboratory analyses

Data Evaluation and Results Interpretation:
- Compile and present relevant data
- Carry out logical analysis of data
- Refine conceptual model for site
- Enumerate implications of results
- Report on findings

2.1.2 Selecting Target Contaminants During Site Investigations

Because of the inherent variability in the materials and the diversity of processes used in industrial activities, it is not unexpected to find a wide variety of contaminants at a contaminated site. As a consequence, there is a corresponding variability in the range and type of hazards and risks that may be anticipated from different contaminated site problems. In general, detailed background information on the critical contaminants of potential concern should be compiled as part of the site investigation program.

The investigation of a potentially contaminated site must provide information on all contaminants known, suspected, or believed to be present at the site. Thus, the investigation should cover all compounds for which the history of site activities, current visible contamination, or public concerns suggest the possibility of contamination by such compounds. Ultimately, the site activity record for which the history of site activities, current visible contamination, or public concerns suggest the possibility of contamination by such compounds. Ultimately, several chemical-specific factors (such as toxicity, density, concentration, mobility, persistence, biodegradability, bioconcentration potential, synergistic/antagonistic effects, potential neutralizing effects, frequency of detection, and naturally occurring background thresholds) are used to further screen and select the specific target contaminants that will become the focus of the detailed site evaluation process.

2.1.3 Contaminant Fate and Transport Considerations

Environmental contamination can be transported far away from its primary source(s) of origin by natural processes, resulting in the possible birth of new contaminated site problems. On the other hand, some natural processes work to lessen or attenuate contaminant concentrations in the environment through mechanisms of natural attenuation such as dispersion/dilution, ion exchange, precipitation, adsorption and absorption, filtration, gaseous exchange, photodegradation, and biodegradation. Typically, environmental fate analysis is used to assess the movement of chemicals between environmental compartments. Simple mathematical models can be used to guide the decisions involved in estimating the potential spread of contaminant plumes. Where applicable, wells or monitoring equipment can then be located in areas expected to have elevated contaminant concentrations and/or in areas considered upgradient and downgradient of a plume.

In general, as pollutants are released into various environmental media, several factors contribute to their migration and transport. A number of important physical and chemical properties affecting the environmental fate and transport of chemical contaminants are annotated in Appendix C. A more detailed discussion of the pertinent factors affecting the environmental fate and/or intermedia transfers for chemical constituents at contaminated sites can be found elsewhere in the literature (e.g., Swann and Eschenroeder, 1983; Lyman et al., 1990).

The affinity that contaminants have for soils can particularly affect their mobility by retarding transport. For instance, hydrophobic or lipophilic contaminants that are migrating in solution may be subject to retardation effects. In fact, the hydrophobicity of a contaminant can greatly affect its fate, which explains some of the different rates of contaminant migration occurring in the subsurface environment. Also, the phenomenon of adsorption is a major reason why the sediment zones of surface water systems may become highly contaminated with specific organic and inorganic chemicals.

In the groundwater system, the solutes in the porous media will move with the mean velocity of the solvent by an advective mechanism. In addition, other mechanisms governing the spread of contaminants include hydraulic dispersion and molecular diffusion (which is caused by the random Brownian motion of molecules in solution that occurs whether the solution in the porous media is stationary or has an average motion). Furthermore, the transport and concentration of the solute(s) are affected by reversible ion exchange with soil grains, chemical degradation with other constituents, fluid compression and expansion, and, in the case of radioactive materials, by radioactive decay.
The degree of chemical migration from a contaminated site depends on both the physical and chemical characteristics of the individual constituents at the site, and also on the physical, chemical, and biological characteristics of the site. Physical characteristics of the contaminants, such as solubility and volatility, influence the rate at which chemicals leach into groundwater or escape into the atmosphere. The characteristics of the site environment (such as geologic or hydrogeologic features) also affect the rate of contaminant migration. In addition, under various environmental conditions some chemicals will readily degrade to substances of relatively low toxicity, while other chemicals may undergo complex reactions to become more toxic than the parent chemical constituent. All other factors being equal, the extent and rate of contaminant movement are a function of the physical containment of the chemical constituents or the contaminated zone. A classical illustration pertains to the fact that a low permeability cap over a contaminated site will minimize water percolation from the surface and therefore minimize leaching of chemicals into an underlying aquifer. Invariably, the fate of chemical compounds released into the environment forms an important basis for evaluating the exposure of biological and ecological receptors to hazardous chemicals.

### 2.1.4 Design of Data Collection and Evaluation Programs

The general types of site data and information required in the investigation of potentially contaminated sites relate to contaminant identities, contaminant concentrations in the key sources and media of interest, characteristics of sources and contaminant release potential, and characteristics of the physical and environmental setting that can affect the fate, transport, and persistence of the contaminants (USEPA, 1989). The design and implementation of a substantive data collection and evaluation program is vital to the effective management of contaminated site problems.

Data are generally collected at several stages of the site investigation, with initial data collection efforts usually limited to developing a general understanding of the site. Typically, a preliminary gas survey using subsurface probes and portable equipment will give an early indication of likely problem areas. Soil gas surveys are generally carried out as a precursor to exploratory excavations, in order to identify areas that warrant closer scrutiny. They can also be used to assist in the delineation of previously identified plumes of contamination. This is an important step to complete prior to the start of a full-scale site investigation.

Gases produced at contaminated sites will tend to migrate through the paths of least resistance. The presence of volatile contaminants or gas-producing materials can be determined by sampling the soil atmosphere within the ground. Installation of a gas-monitoring well network, in conjunction with sampling in buildings in the area, can be used to determine the need for corrective measures. This information can be used to determine the possibility for human exposures and to determine appropriate locations for monitoring wells and gas collection systems.

On-site vapor screening of soil samples during drilling can provide indicators of organic contamination. For example, organic vapor analyzer/gas chromatograph (OVA/GC) or gas chromatograph/photoionization detector (GC/PID) screening provides a relative measure of contamination by volatile organic chemicals. Also, predictive models can be used to estimate the extent of gas migration from a suspected subsurface source. This information can subsequently be used to identify vapor analyses on-site can also be helpful in selecting screened intervals for monitoring wells.

In areas where the contamination source is known, the sampling program should be targeted around that source. Normally sampling points should be located at regular distances along lines radiating from the contaminant source. Provisions should also be made in the investigation to collect additional samples of small, isolated pockets of material which are visually suspect.

In general, a phased sampling approach encourages the identification of key data needs as early in the site investigation process as possible. This ensures that the data collection effort is always directed toward providing adequate information that meets the data quantity and quality requirements of the study. As a basic understanding of the site characteristics is achieved, subsequent data collection efforts focus on identifying and filling in data gaps. Any additionally acquired data should be such as to further improve the understanding of site characteristics and also consolidate information necessary to effectively manage the contaminated site problem. In this way, the overall site investigation effort can be continually rescoped to minimize the collection of unnecessary data and to maximize the quality of data acquired. Overall, the data gathering process should provide a logical, objective, and quantitative balance between the time and resources available for collecting the data and the quality of data, based on the intended use of such data.

### 2.1.5 Analyzing Site Information

The analysis of previously acquired and newly generated data serves to provide an initial basis to understanding the nature and extent of contamination which, in turn, aids in the design of appropriate corrective action programs for contaminated sites. Consequently, at any reasonable stage of a site investigation, all available site information should be compiled and analyzed to develop a conceptual model for the site. This representation should incorporate contaminant sources and "sinks", the nature and behavior of the site contaminants, migration pathways, the affected environmental matrices, and potential receptors (Figure 2.1). In fact, the development of an adequate conceptual site model (CSM) is an important aspect of the technical evaluation scheme necessary for the successful completion of a site investigation. It integrates geologic and hydrologic information, and provides a basis for human health and ecological risk assessments. The CSM is also relevant to the development and evaluation of corrective action programs for potentially contaminated sites.

Several variables and parameters are important to the design of a realistic CSM that will meet the overall goals of the corrective action program anticipated for a potentially contaminated site (Box 2.2). In general, the CSM should be appropriately modified if the acquisition of additional data and new information necessitates a redesign. Further discussions and illustrations of the framework for developing CSMs are given in Chapter 4.

### 2.2 A PHASED APPROACH TO THE INVESTIGATION OF POTIENTIALLY CONTAMINATED SITE PROBLEMS

Programs designed to investigate and remedy potentially contaminated site problems typically consist of a number of phases. These phases reflect the different degrees of difficulty in the corrective action and risk management decisions for the site.
Environmental site assessments conducted as part of a corrective action investigation for potentially contaminated sites may be classified into the following general phases:

- “PHASE I” Investigation, or Preliminary Site Assessment, consisting of a reconnaissance site appraisal and reporting.
- “PHASE II” Investigation, or Comprehensive Site Assessment, comprising of a site investigation (that involves contamination and environmental damage assessment) and a preliminary feasibility study of corrective measures.
- “PHASE III” Investigation, or Remedial Measures Design and Implementation, incorporating a focused feasibility study and the detailed evaluation of site restoration measures.

In general, the objective of the initial phase (which is comprised of basic background information gathering) should be to determine the history of the site with respect to contamination sources and any relevant characteristics of the site that are readily obtainable from available records, reports, and interviews. The intermediate phase (involving a site characterization) has the primary objectives of defining the vertical and lateral extents of contamination, understanding how the Contaminants are...
affected by hydrogeologic conditions, and providing the data necessary to design appropriate and applicable remedial measures. The final phase (that may include a risk valuation of remedial alternatives as part of the focused feasibility study) targets the development, selection, and implementation of appropriate corrective action plans for the site. Table 2.2 summarizes the requirements of the different levels of effort associated with the site assessment process.

### TABLE 2.2  Summary Requirements of the Site Assessment Process

<table>
<thead>
<tr>
<th>Level of investigation</th>
<th>Purpose of investigation</th>
<th>Typical “add-on” tasks performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>HASE I: Preliminary site assessment</td>
<td>To provide a qualitative indication of potential contamination at a site</td>
<td>Records search, including geologic and hydrogeologic literature search, aerial photo reviews, review of archival and regulatory agency records (to define the historical uses of site), and anecdotal reports (on site history and practices as made available by former employees, local residents, and local historians) Site inspection/reconnaissance survey (to define present conditions at the site) Personal interviews (to supplement historical use data) Written report of findings (to document results and recommendations) Sampling of potentially impacted media at the surface Subsurface borings, well installations, and groundwater sample collection Sample analysis to identify and quantify contaminants Evaluation of sampling results and detailed report of findings, with conclusions Development of remediation goals and cleanup criteria Identification of alternative methods/technologies for site remediation Screening of alternatives in order to select those that are most feasible option Evaluation of alternatives in terms of technical performance and cost-effectiveness Design and implementation of remedial options and monitoring programs</td>
</tr>
<tr>
<td>HASE II: Initial site investigation</td>
<td>To identify the known or suspected source(s) of contamination</td>
<td>Records search, including geologic and hydrogeologic literature search, aerial photo reviews, review of archival and regulatory agency records (to define the historical uses of site), and anecdotal reports (on site history and practices as made available by former employees, local residents, and local historians) Site inspection/reconnaissance survey (to define present conditions at the site) Personal interviews (to supplement historical use data) Written report of findings (to document results and recommendations) Sampling of potentially impacted media at the surface Subsurface borings, well installations, and groundwater sample collection Sample analysis to identify and quantify contaminants Evaluation of sampling results and detailed report of findings, with conclusions Development of remediation goals and cleanup criteria Identification of alternative methods/technologies for site remediation Screening of alternatives in order to select those that are most feasible option Evaluation of alternatives in terms of technical performance and cost-effectiveness Design and implementation of remedial options and monitoring programs</td>
</tr>
<tr>
<td>HASE III: Expanded site investigation (or remedial investigation/feasibility study)</td>
<td>To define the hydrolotography of the region and direction of contaminant plume migration</td>
<td>Records search, including geologic and hydrogeologic literature search, aerial photo reviews, review of archival and regulatory agency records (to define the historical uses of site), and anecdotal reports (on site history and practices as made available by former employees, local residents, and local historians) Site inspection/reconnaissance survey (to define present conditions at the site) Personal interviews (to supplement historical use data) Written report of findings (to document results and recommendations) Sampling of potentially impacted media at the surface Subsurface borings, well installations, and groundwater sample collection Sample analysis to identify and quantify contaminants Evaluation of sampling results and detailed report of findings, with conclusions Development of remediation goals and cleanup criteria Identification of alternative methods/technologies for site remediation Screening of alternatives in order to select those that are most feasible option Evaluation of alternatives in terms of technical performance and cost-effectiveness Design and implementation of remedial options and monitoring programs</td>
</tr>
<tr>
<td>HASE III: Remedial measures, investigation and corrective action implementation</td>
<td>To recommend the site restoration method which is most feasible in terms of technical performance and cost-effectiveness</td>
<td>Records search, including geologic and hydrogeologic literature search, aerial photo reviews, review of archival and regulatory agency records (to define the historical uses of site), and anecdotal reports (on site history and practices as made available by former employees, local residents, and local historians) Site inspection/reconnaissance survey (to define present conditions at the site) Personal interviews (to supplement historical use data) Written report of findings (to document results and recommendations) Sampling of potentially impacted media at the surface Subsurface borings, well installations, and groundwater sample collection Sample analysis to identify and quantify contaminants Evaluation of sampling results and detailed report of findings, with conclusions Development of remediation goals and cleanup criteria Identification of alternative methods/technologies for site remediation Screening of alternatives in order to select those that are most feasible option Evaluation of alternatives in terms of technical performance and cost-effectiveness Design and implementation of remedial options and monitoring programs</td>
</tr>
</tbody>
</table>

The comprehensive site assessment typically comprises a site investigation (SI) and/or a remedial investigation/feasibility study (RI/FS). In general, these site assessment are usually involved in sampling and testing to identify the types of contaminants, analyzing preselected or priority pollutants, and determining the horizontal and vertical extents of the contaminant. This typically includes subsurface investigations, soil and water sampling, laboratory analyses, tank testing, and other relevant engineering investigations to quantify potential risks previously identified in the PA.

The SI is designed to verify findings from the PA, to determine the presence or absence and the extent of contamination at the site, and to identify probable remediatio
measures. Typically, the investigation identifies specific contaminants, their concentrations, the areal extent of contamination, the fate and transport properties of the contaminants, and the potential migration pathways of concern.

In an expanded SI, the RI strives to improve the initial site characterization. The FS investigates the most cost-effective methods of remediation that will protect public health, the environment, and public and private property under applicable and appropriate standards or regulations.

At a minimum, a comprehensive site assessment will include the collection and analysis of as many soil samples as necessary to determine the full extent of the contamination. If contamination is found to be confined to the unsaturated (vadose) zone, then no groundwater investigation may be required; otherwise, groundwater investigation is initiated. The level of detail for the data collection activities will be site-specific, and is dependent on the degree of soil and groundwater contamination found at the site.

2.2.2.1 PHASE IIA Investigations

An initial Phase II assessment will normally be used to confirm whether or not a release has occurred. This is accomplished by implementing a limited program to collect and analyze appropriate site samples. To complete this process, a sampling plan must first be developed. Subsequently, site visits are conducted during which sampling activities will be carried out. The results of this initial comprehensive site assessment will determine the need for a “further-response-action” or a “no-further-response-action”. A Phase IIA investigation will generally conclude that either:

1. No evidence of contamination was discovered, and no further investigation is recommended; or
2. Contamination that may require remediation has been found, and a Phase IIB investigation is recommended.

In fact, if the site is determined to pose significant public health or environmental risks, extensive studies will typically be required to quantify the magnitude of contaminants present, delineate the limits of contamination, characterize in detail the specific chemical constituents present at the site, and assess the fate and transport properties of the specific substances at the site.

2.2.2.2 PHASE IIB Investigations

Where necessary, an expanded Phase II assessment is conducted with the main objective to characterize the contamination confirmed from the initial Phase II investigations. The characterization process involves specifying the type of contamination present, assessing the three-dimensional Occurrence of the contamination, evaluating the contaminant fate and transport, determining possible human and ecological “receivers” potentially at risk, estimating the risks posed to the populations at risk, establishing a database to facilitate documentation of changes in the occurrences of the contamination, and conducting a preliminary screening of corrective measures. A Phase IIB investigation will generally conclude that either:

1. No evidence of extensive contamination was discovered that requires remediation, and no further investigation is recommended; or
2. Contamination that may require remediation has been found, and a Phase III investigation is recommended.

Typically, the Phase IIB assessment will generate a report made up of a site characterization, a risk assessment, and an evaluation of mitigation and remediation options with an indication of the preferred corrective action plan.

2.2.3 PHASE III Investigations

The remedial measures study involves an evaluation of corrective action programs previously identified during the expanded comprehensive site assessment, an engineering design of the selected remedial plan, and the implementation of the cleanup or mitigation measures necessary to abate public health and environmental concerns. This also includes a review of the environmental and public health risks and costs associated with a variety of proposed remedial alternatives. The documentation offered will facilitate the development of appropriate corrective action programs consistent with appropriate regulatory guidelines. The selected remedy will fulfill the jurisdictional requirements for environmental conditions at the site, and should present minimal risk to the environment and/or to public health.

The Phase III assessment will typically report on the preferred corrective action plan, incorporating the design and implementation of the remedial action plans and postremediation monitoring. This level of the site assessment will also generally include remediation cost estimates as part of the detailed evaluation process for the alternative remedial options identified for the site. This aspect of the assessment will involve evaluating the feasibility of various corrective action strategies applicable to the site scenario, and also evaluating the impact of the mitigated site on the current and future land uses at and near the site.

2.3 THE SITE ASSESSMENT DECISION PROCESS

Prior to the development of a corrective action plan for a contaminated site problem, a site assessment must be conducted to determine the true extent of contamination at the site. The use of a systematic approach will result in an optimal data gathering and evaluation process that meets uncompromising data quantity and quality objectives (Figure 2.2). Such a strategy will indeed help address potentially contaminated site problems in a cost-effective manner.

In general, once a diagnostic assessment of possible environmental contamination problems is completed for a potentially contaminated site, plans can be made towards the implementation of effective corrective actions, where warranted. The underlying goal in conducting site assessments is to determine an appropriate level of effort in the corrective action required for a site at which contamination is suspected, or known to have occurred. The type of corrective action selected for the contaminated site problem will depend on the nature of contamination, the amount of contamination that could safely remain at the site following site restoration, and several other site-specific factors.
An illustrative example of a corrective action investigation

This section illustrates the nature of decision elements typically employed in the investigation of potentially contaminated sites. The example discusses a potential contamination problem at a small shopping center located in a rural township that depends almost exclusively on groundwater from a contiguous aquifer for its water supplies. The trigger for this investigation is the discovery that dry-cleaning solvents have spilled on concrete floor slabs at a dry-cleaning facility within this mini-mall.

**Background** — A preliminary environmental site assessment carried out for the Village Shopping Center (VSC) indicated the potential for soil and groundwater contamination at this facility as a result of releases from dry-cleaning and laundry activities at one section of the mall. A follow-up phase II-type assessment conducted for the site confirmed the presence of elevated levels of perchloroethylene (PCE) in the sampled soils. The soils beneath the facility location consist predominantly of fine sands, or fine sand with occasional gravels. Some plastic liner materials (likely to have been used as a plastic moisture barrier beneath the concrete floor slabs) were found in some of the exploratory borings at the site. It is believed that the plastic liner materials found beneath the concrete floor may have prevented extensive contamination of the subsurface environmental compartments.

**Recommendations for the corrective action investigation** — Since PCE spills would have occurred on the concrete floors at the VSC facility, and because the plastic liner material may have been serving as a “barrier” against further contaminant migration, it is very possible that any PCE encountered in the exploratory soil borings could have been introduced into the soil after the barrier was broken during the soil sample coring activities. If this hypothesis is true, then the extent of soil contamination may be even less than suspected; in addition, the possibility of any extensive groundwater contamination can also be ruled out. Under such circumstances, a more detailed assessment may indicate that no extensive and expensive remediation or cleanup program is necessary for the VSC facility. In fact, this reasoning will also support the importance of studying complete building plans/layouts before any drilling activities that could actually facilitate the spreading of contaminants that would otherwise be sitting as a more easily removable free product.

To complete the requisite investigations for the VSC facility that will allow for appropriate corrective action decisions, a number of issues must be fully explored and evaluated, including the following:

1. Groundwater beneath the site should be investigated in order to complete the site assessment. This is because soils beneath the site have already been impacted, and PCE is reasonably mobile in the type of soil formations at this site. That is, considering the mobility of PCE and the sandy nature of soils found at the VSC facility, the possibility of a contaminated aquifer beneath the facility cannot be ignored. In particular, if it cannot be established that the liner materials may have prevented the PCE from migrating further into the subsurface environment, then the groundwater system beneath the site should be fully investigated. On the other hand, if it can be positively established that the plastic liner material did serve to prevent or minimize PCE migration into the subsurface environments, then a different set of exposure scenarios may be

A project manager needs to be cautious in accepting the results of any site investigation activity as being an absolute indicator of the true situation at a suspect site. In practice, rather than simply walk away from a site purported to be “clean”, it often is a good idea to implement some form of monitoring program for the candidate site even when no evidence of contamination has been found during the site assessment. This is important if for no other reason than to account for uncertainty, because even a carefully executed site investigation program may still miss some isolated pockets of contaminants that may become long-term release sources and therefore a

**MANAGEMENT OF CONTAMINATED SITE PROBLEMS**

**DIAGNOSTIC ASSESSMENT OF CONTAMINATED SITE PROBLEMS**

**Potential risks apparent?**

- Yes
  - Perform an initial site investigation (Phase II[A])
  - Significant risks apparent?
    - Yes
      - Remediation required?
        - Yes
          - Design & Implement limited monitoring program
        - No
          - Remediation required?
            - Yes
              - Design & Implement monitoring program for performance evaluation
            - No
              - Implement site closure (i.e., no-further-response -action) plans
      - No
        - Remediation required?
          - Yes
            - Design & Implement limited monitoring program
          - No
            - Implement site closure (i.e., no-further-response -action) plans
    - No
      - Develop institutional control & corrective action measures

**Recommendations for the corrective action investigation** — Since PCE spills would have occurred on the concrete floors at the VSC facility, and because the plastic liner material may have been serving as a “barrier” against further contaminant migration, it is very possible that any PCE encountered in the exploratory soil borings could have been introduced into the soil after the barrier was broken during the soil sample coring activities. If this hypothesis is true, then the extent of soil contamination may be even less than suspected; in addition, the possibility of any extensive groundwater contamination can also be ruled out. Under such circumstances, a more detailed assessment may indicate that no extensive and expensive remediation or cleanup program is necessary for the VSC facility. In fact, this reasoning will also support the importance of studying complete building plans/layouts before any drilling activities that could actually facilitate the spreading of contaminants that would otherwise be sitting as a more easily removable free product.

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2. Site conditions should be adequately characterized, in order to fully define the lateral and vertical extents of the PCE contamination. In this regard, it is noted that PCE has rather low adsorptivity to soil; consequently, if released to soils, it will generally be subject to an accelerated migration into the groundwater. In particular, PCE can move rapidly through sandy soils and may therefore reach groundwater more easily in the type of geological formations found at the VSC facility.

3. Risk assessment procedures are typically used to establish cleanup objectives for contaminated environmental media requiring corrective actions and/or for the implementation of risk management programs for contaminated sites. Such an assessment should be used to help focus corrective action assessments and risk management plans for the VSC facility. The site-specific risk assessment may also include the development of appropriate site restoration goals with reference to site conditions, land uses, and exposure scenarios pertaining specifically to this shopping center and its vicinity. It is believed that the development of site-specific cleanup levels can result in significant cost savings in this type of investigation.

A complete characterization of the “contaminated zone” at the site should facilitate the screening and selection of the best available technology for a remedial action plan that is developed for the VSC facility. Prior to implementing any remediation plan for this site, appropriate risk-based cleanup criteria should be developed and compared with the current levels of contamination present at the site (i.e., under the baseline conditions). Based on such criteria, it may become apparent under the appropriate types of exposure scenarios that no cleanup is warranted. In fact, even if it is determined that some degree of cleanup is required, the cleanup criteria developed will aid in optimizing the efforts involved, so as to arrive at more cost-effective solutions than could otherwise have been achieved.

REFERENCES


