CONTAMINATED SITE CHARACTERIZATION AND MONITORING

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Contents

Summary

This chapter presents a review of site characterization and monitoring; how it has been performed in the past, in the present, and monitoring trends. Aspects of monitoring protocols are addressed to provide a systematic and reliable pattern of procedures for characterizing a wide variety of site conditions. The generic aspects of a site-monitoring

protocol include sampling objectives, constraints, logistical support, an effective sampling protocol, monitoring parameters, data management, screening of alternatives, feasibility studies, quality assurance, quality control, and health and safety. Also, elements of sampling protocol are discussed, including statistical sampling requirements, parameters to monitor, data collection methods, sample handling, preservation, transportation, and storage. In general, available technologies for site characterization have focused mostly on contaminants in groundwater. Those technologies are labor intensive. In general, site investigation and monitoring are still a highly labor-intensive task (laboratory and field analysis) as statistical criteria have to be fulfilled, which in turn requires a large amount of soil sampling to identify trends that verify contaminant reduction.

Also, many of the available technologies are unable to detect contamination in the vadose zone in real time and *in situ*. The monitoring of contaminant transport in the vadose zone is recent, and significant research has been devoted to developing methods and techniques to measure contaminant transport therein. In this chapter, aspects of assessment, performance, and post-closure site characterization are discussed, as well as trends in equipment development. The main focus of new innovative technologies is to directly monitor *in situ* and real-time changes in contaminant concentrations at contaminated sites in order to achieve a more cost-effective protection of public and ecological health. Finally, research needs on site characterization are identified, such as the need for more technical guidance. The discussion presented herein is focused primarily on hazardous waste, including organic and inorganic contaminants of anthropogenic origin. Other technologies and methodologies are warranted for sites where radiation is of concern (see *Radiation Monitoring*).

1. Introduction

From the geoenvironmental point of view, one can identify three monitoring objectives in contaminated site characterization: assessment, evaluation and performance. In assessment monitoring, one seeks an assessment of the physical site conditions, the likely contaminants present, and their extent. In evaluation monitoring, data are provided to evaluate alternative designs in a remediation program. Performance monitoring involves an appraisal of the effectiveness of the applied remedial treatment (i.e., the contaminant levels and rate of reduction or stabilization). Also, monitoring can be performed in response to specific activities, such as a post-closure requirement for a municipal or hazardous-waste landfill. In all cases, it is very important to acquire reliable site contamination data such as contaminant mobility and concentration within the soil matrix. Data for a given soil and their respective geochemical parameters are obtained by collecting and analyzing soil, soil-gas, and soil porewater samples. The interpretation of results is used as the basis for development of an action plan to mitigate risks posed by on site contaminants.

During site characterization and monitoring, it is important to note that:

- It is a site-specific task, and there might be few available technical guidance documents to rely on, and the available technical documents may not always be adequate;
- The operational team may change during the monitoring process;

- As a contaminated site is investigated, new information may become available that influences which methods and techniques are most relevant;
- To maximize the likelihood of meeting financial constraints, accurate feasibility studies should be conducted;
- While general guidance documents may be used, all decisions should be made on a site-by-site basis; and
- Site conditions may be subject to significant temporal and spatial change.

Notwithstanding innovative developments, the monitoring process is still a complex, labor intensive, and expensive site-specific task. The majority of contaminated sites involve different variables, such as soil stratigraphy, soil chemistry, geology, topography, water, and several different contaminants, so there is no single solution, rather a broad framework that can be used to develop a sound monitoring plan.

Finally, it is important to have control samples to understand the significance of sampling and monitoring data with respect to background conditions. Control samples must have similar characteristics to those that are contaminated and should be taken at a location upwind, upstream, and/or upgradient from the site of concern. Travel between contaminated and control sites should be avoided in order to minimize potential cross-contamination by workers, equipment, and vehicles. Gas monitoring and groundwater monitoring are important elements of site characterization and are addressed elsewhere in more detail (see *Soil Contamination Monitoring* and *Groundwater Monitoring*).

2. Site Characterization and Monitoring Protocol

A cost-effective site characterization program should be planned systematically with clear objectives. Elements of the program will include monitoring objectives, constraints for logistical support, data management, and sampling procedures. The overall program must seek to maximize the acquisition of quality data while meeting financial and time constraints. Omission of such elements has prevented many characterization and monitoring efforts from meeting their objectives. Below are examples of questions to be answered during the development of a site characterization and monitoring program:

- What are the objectives of a site characterization program?
- How long does the system need to function?
- What are the variables to be monitored?
- How long is long-term in monitoring?
- How should data storage and data management be performed?
- How should the accumulated data be analyzed and interpreted?
- What are the consequences of monitoring system failure?

Figure 1 presents the important steps in performing a site characterization plan while Figure 2 shows the steps to be performed during the execution of a sound monitoring project. It is important to note that a site characterization and monitoring plan is typically one that evolves and improves as new information becomes available.

2.1. Site Characterization Objectives

Objectives are broad primary statements that establish the goals and focus of a project. In most cases, site characterization plans are tailored:

- To check the rates of change in the soil contaminants
- To verify the effectiveness and performance of adopted remedial actions
- To quantify the presence of contaminants in the soil
- To assess the risks of those soil contaminants on health

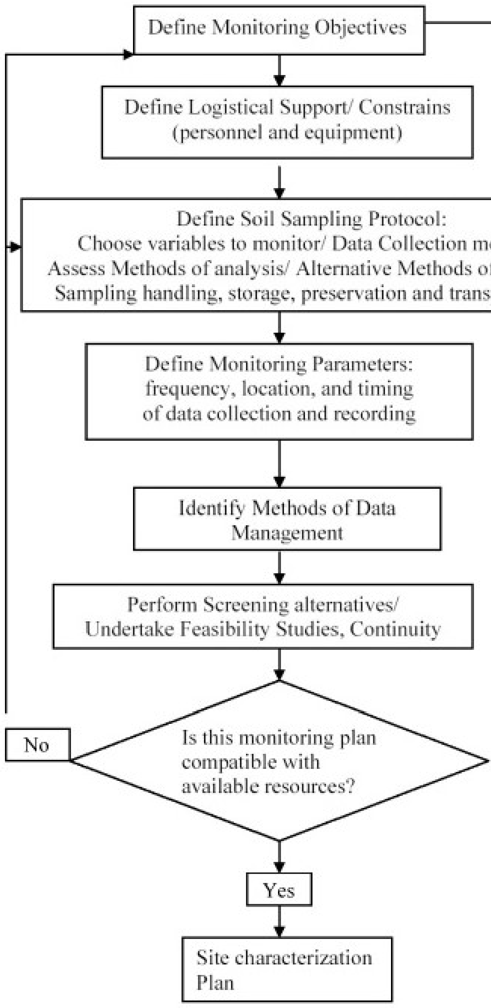

Figure 1. Development of a sound monitoring protocol

After identifying the project objectives, subtasks are defined. Subtasks are defined with greater detail and reflect site-specific needs. It is at this phase of a project that site characterization and monitoring priorities are quantified. This includes deciding on which contaminants constitute a concern and at what level of concentration relative to background. The region of interest must be defined in terms of space and time—short- or long-term.

2.2. Logistical Support

Personnel and material support are essential to achieve a cost-effective monitoring program that minimizes uncertainties in subsequent laboratory analyses. Practically, this support refers to that provided on-site during sampling or *in situ* testing, off-site at a laboratory, and throughout the chain of custody (see *Laboratory-based Analytical Techniques*). Data should be collected in a consistent manner with adequate methods of data storage and retrieval in place.

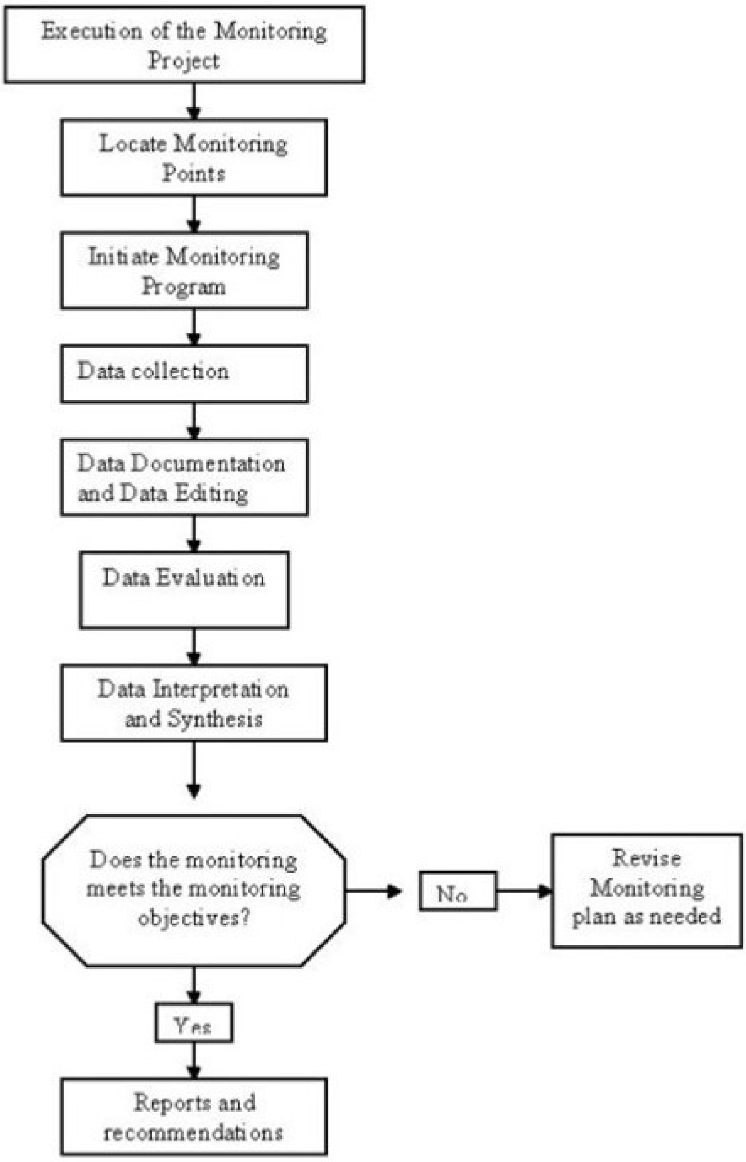

Figure 2. Execution of a monitoring protocol

Moreover, the personnel involved in these tasks must have commensurate training, licenses and/or certification as necessary. Basic questions and concerns regarding the selection and quality of a proposed environmental laboratory to be used in connection with a site characterization plan include:

- Can the laboratory handle the quantity and type of analysis for the project monitoring within given time constraints?
- Does the laboratory follow required regulatory standards, including explicit sample collection instructions, preservation techniques, etc.?
- Are data validated?

It may be desirable to conduct an independent assessment of the data sent by the laboratory to ensure that results are reasonable. A visit to a laboratory before the award of a contract to review procedures, equipment, and staff capabilities is advisable. Additionally, maintaining communication between the project site and the laboratory may minimize sample confusion and integrity while in transit.

Independent experts should be arranged in order to make an independent analysis of the data sent by the laboratory to make sure that those data make sense and are valid.

2.3. Constraints

Monitoring projects can take place in complex and challenging environments, requiring the use of different equipment under various operational conditions. Among the several constraints to which a project may be subject, only equipment and climate are discussed herein. The soil sampling equipment employed in site characterization depends on the soil type and depth, acceptable level of disturbance, and nature of subsequent testing. A list of equipment requirements should be written. To assist with this task, it is useful to answer questions such as the ones stated below:

- Is the equipment operated manually/mechanically or power driven?
- Is on-site electrical power available? What are the possible power sources?
- Are resources for on-site equipment maintenance and support adequate?
- Have measures been taken to ensure that equipment and material will not result in contamination or cross-contamination?
- What procedures should be adopted in case of power failure?

Given the importance of continuous data acquisition and system control, one of the most critical constraints is that imposed by a power or battery failure on site, especially if the site is located far away from major cities or other resources. Other constraints are those connected with maintenance problems such as repair or replacement of equipment components. Prior to the commencement of a project, a list of critical components and their suppliers should be developed.

Climate and weather conditions exert significant influence during the sampling procedure, placement of equipment, and/or during the readings of such equipment. Consideration of equipment and material performance under adverse conditions will minimize potential delays. For example, freezing conditions may necessitate measures that prevent fuel freezing, while precipitation events may create hazardous conditions associated with drainage or lightning. While easily forgotten in the planning stages of a project, poor weather conditions render sampling and field observation difficult. High winds create unfavorable conditions for soil sampling. Personnel should position themselves upwind during sampling. When sampling for moisture content, particularly under low-humidity or high-temperature conditions, special care should be taken to minimize soil exposure to avoid sample desiccation.

2.4. Soil Sampling Protocol

The sampling protocol covers all equipment preparation, project personnel, method selection, and the entire implementation. Effective planning involves a critical assessment of all relevant site-specific details. Several important issues should be addressed during the development of an effective sampling protocol, including detailed consideration of the sampling objectives, approach and collection methods (i.e., packing, labeling/documenting, sample preservation techniques, and analytical methods). In practice, the following information should be recorded: sampling location, sampling date, sampling time, sample identification number, sampler's name, sampling type, preservation used, time of preservation, and other relevant *in-situ* observations, such as wind speed and direction. Indeed, records at a contaminated site can be extremely numerous on any site of reasonable size. The challenge is to store, check, analyze, and present the records in a way that is not overly time consuming. The use of relational databases and graphical information systems may be used for this purpose (see *Applications of Geographic Information Systems*).

The principal objective of soil sampling is to obtain a small and informative portion of the statistical population being investigated (on the saturated and unsaturated zones, as well as the soil porewater) so that contaminant levels and the important contaminant migration pathways and the affected media can be established. The soil sampling process by itself is demanding and labor intensive. The greatest disadvantage of soil sampling is that it is a destructive method, and it is not possible to retrieve replacement or substitute samples at the same location that was originally sampled. Soil analyses are generally expensive, hence, sampling should be optimized with a balance of efficiency and care. It is not useful to carefully analyze a sample that has been taken carelessly and is unrepresentative of the strata under investigation. Also, sampling plans may have to modified and refined as new data become available.

2.4.1. Statistical Sampling Requirements

This discussion of statistical analysis is intentionally conceptual to aid the reader in appreciating the overall planning process. Detailed mathematical formulations associated with statistical sampling requirements may be found elsewhere (see Geostatistical Analysis of Monitoring Data). Decisions regarding a site characterization and monitoring project are based on data and as such, the extent to which it is reliable must be quantified. Spurious data may lead to flawed decisions, and consequently, the loss of money and time. Statistical analyses are used to ensure data integrity. Frequently, the significance of data relative to hypothesis testing is the focus of a sampling plan. It is much more common to observe how researchers have been striving so hard in demonstrating the significance of data (which were not collected!) to test the statistical hypothesis than to discuss the meaning of the statistical hypothesis, or even, what are sound objectives upon which the hypothesis have been elaborated. Thus, it is more relevant to discuss the meaning of the statistical hypothesis and the objectives upon which the hypothesis was developed. Indeed, the soundness of a statistical analysis is dictated by the objectives of the monitoring plan. Defining a hypothesis, *a priori*, helps to ensure that the experimental units and sample population are clearly defined, and that there is sufficient replication to allow statistical analysis. In principle, a statistical analysis defines the extent to which objectives are met. Procedurally, this process follows the same outline as proposed by Galileo Galilei, the well-known scientific method, which includes the following steps: identification of problem, the establishment of hypothesis, the establishment of a model, tests of hypothesis, and finally the formation of conclusions. To apply this scientific model to statistical requirements associated with site characterization and soil sampling, these steps may be rewritten as: question, hypothesis development; sampling design, statistical analysis, tests of hypothesis, interpretation, and presentation of results.

As shown in the order of appearance, the clear development of a question, which corresponds to specific objectives, must occur prior to statistical analysis. Statistical analysis is typically employed to assess and determine parameters such as accuracy, precision, the significant number of sample replicates, and sample representativeness. The aim is often to obtain samples representative of the population while reducing the opportunity for bias in sample selection.

Usually, errors committed during sampling are random and their cumulative effects may cancel out. In contrast, bias is an error in a consistent direction with cumulative effects that do not cancel out. If the sampling protocol is changed during the course of a project, the information gathered may be biased. The effect of this bias must then be considered during subsequent data analysis and interpretation. It is desirable to obtain unbiased data so that valid comparisons can be made between the values of monitored parameters and background. Sampling plans commonly used for soil monitoring programs include random (simple or stratified), systematic, grid, or target sampling, and those developed based on judgement or experience. Details are available in the literature. However, those in common use are briefly described herein. Random sampling provides the best estimate of population characteristics as each element in a complete data set has an equal probability of selection. Stratified random sampling can be used when sufficient information is available about the population to stratify it into appropriate groups for study. The first step is to separate the population into groups with the required characteristics, and then to select a random sample within the group.

The most common errors are those associated with sampling, such as contamination introduced during sampling, sample degradation during transportation, variation in subsampling to obtain a quantity appropriate for analysis, fluctuation in wet chemistry before the subsample is analyzed, variation in the analytical instrument, and any other human errors. Any of those sources might occasionally give a large deviation—and this underscores the need for a statistical distribution function. Although the Gaussian (or normal) distribution enjoys widespread use, recent findings indicate that the results will often result in a significant overestimation, and may be overly conservative, because a few high values (i.e., outliers) exert excessive influence on the characterization of the distribution. Currently, there is increasing support for the lognormal statistical distribution. In summary, the distribution methods, normal or lognormal distribution are used to estimate summary statistics. Unfortunately, data rarely fit these assumed distributions.

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Biographical Sketches

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Hilary I. Inyang is the Duke Energy Distinguished Professor of Environmental Engineering and Science, Professor of Earth Science and Director of the Global Institute for Energy and Environmental Systems at the University of North Carolina-Charlotte. Prior to his current position, he was University (titled) Professor, Dupont Young Professor and Director of the Center for Environmental Engineering, Science and Technology (CEEST) at the University of Massachusetts, Lowell. Previously he taught at George Washington University, Washington, D.C; Purdue University, West Lafayette, Indiana; and University of Wisconsin, Platteville. Prof. Inyang also served at the U.S. Environmental Protection Agency (1991-1993) as a Senior Geoenvironmental Engineer and subsequently as the President of Geoenvironmental Design and Research (GDR) Inc., Fairfax, VA, a small research firm that he founded in 1993. His research and allied professional activities have focused on waste containment systems, contaminant leachability, soil/contaminant physico-chemical interactions, natural disaster mitigation techniques, rock fragmentation techniques for energy installations and underground space, and energy/environmental policy. His projects have been sponsored by federal agencies such as US. Department of Defense, U.S. Environmental Protection Agency, U.S. Department of Agriculture, National Oceanic and Atmospheric Administration, Federal Highway Administration, the United States Agency for International

Development, and corporations such as Duke Energy Corporation, and Dupont Corporation. Through basic and applied research, associated technical activities, advisory roles in state, national and international government agencies, and education, Prof. Inyang has made significant contributions to the evolution of the new field of geoenvironmental engineering. He has authored/co-authored more than 140 research articles, book chapters, federal design manuals and the textbook- Geoenvironmental Engineering: principles and applications.