Sites contaminated by chlorinated solvents present a daunting environmental challenge. Chlorinated solvents are prevalent and persistent groundwater contaminants and are present at tens of thousands of contaminated sites worldwide. They are also among the most difficult groundwater contaminants to remediate, especially at sites with dense, nonaqueous-phase liquid (DNAPL) in the source zone. Restoring sites contaminated by chlorinated solvents to typical regulatory criteria (low parts-per-billion concentrations) within a generation (~20 years) has proven difficult. Complete restoration of such sites may require prolonged treatment and involve several remediation technologies. An integrated and strategic approach to chlorinated solvent– contaminated sites will support significant progress within a generation. Such an approach is built on a thorough understanding of the site and clear descriptions of achievable objectives. The resulting adaptive management strategy may also require transitioning from one remedy to another as the optimum range of a technique is passed. Targeted monitoring should be used and progress toward objectives periodically reevaluated.

This is not to say that complete restoration to such standards is impossible. To the contrary, there are examples where restoration to maximum contaminant levels (MCLs) or similar numeric standards has been achieved at chlorinated-solvent sites. However, most of these sites do not have significant DNAPL source zones that would allow removal by excavation. In fact, during preparation of this document, not a single example of a chlorinated-solvent site closure was identified where closure was based on achievement of MCLs throughout the entire site (including the DNAPL source zone) and without excavation.

For those chlorinated-solvent sites that have received regulatory closure, it was generally not based on complete restoration throughout the entire site. For example, the U.S. Environmental Protection Agency (USEPA) reports, “Sites profiled illustrate that addressing DNAPL source zones can lead to regulatory closure and, as is the case in six sites, unrestricted use” (USEPA 2009a). USEPA further reports, “Although this paper does not attempt to resolve this issue (e.g., benefits of source removal), it does provide information that illustrates instances where source reduction has contributed to achieving cleanup goals (maximum contaminant levels…).”

Compounding the challenge is the uncertainty associated with the benefits of partial source removal and the general lack of interim regulatory metrics or objectives to help define and incentivize partial source cleanup success. For example, some studies suggest that anything less than 80%–90% DNAPL source removal will result in only modest dissolved-phase contaminant concentration reductions in the downgradient plume (Falta, Basu, and Rao 2005; Sale and McWhorter 2001). Chapman and Parker (2005) suggest that even with complete DNAPL removal, contaminant diffusion into low-permeability zones can be a continuing source leading to dissolved-phase contaminant concentration reductions of only 1–3 orders of magnitude (OoMs). At the same time, 5 or more OoMs reduction may be needed to fully restore the site (Figure 1-1). USEPA (2009a) has concluded that “…the benefits of DNAPL source removal, especially partial source removal, are still being debated.”

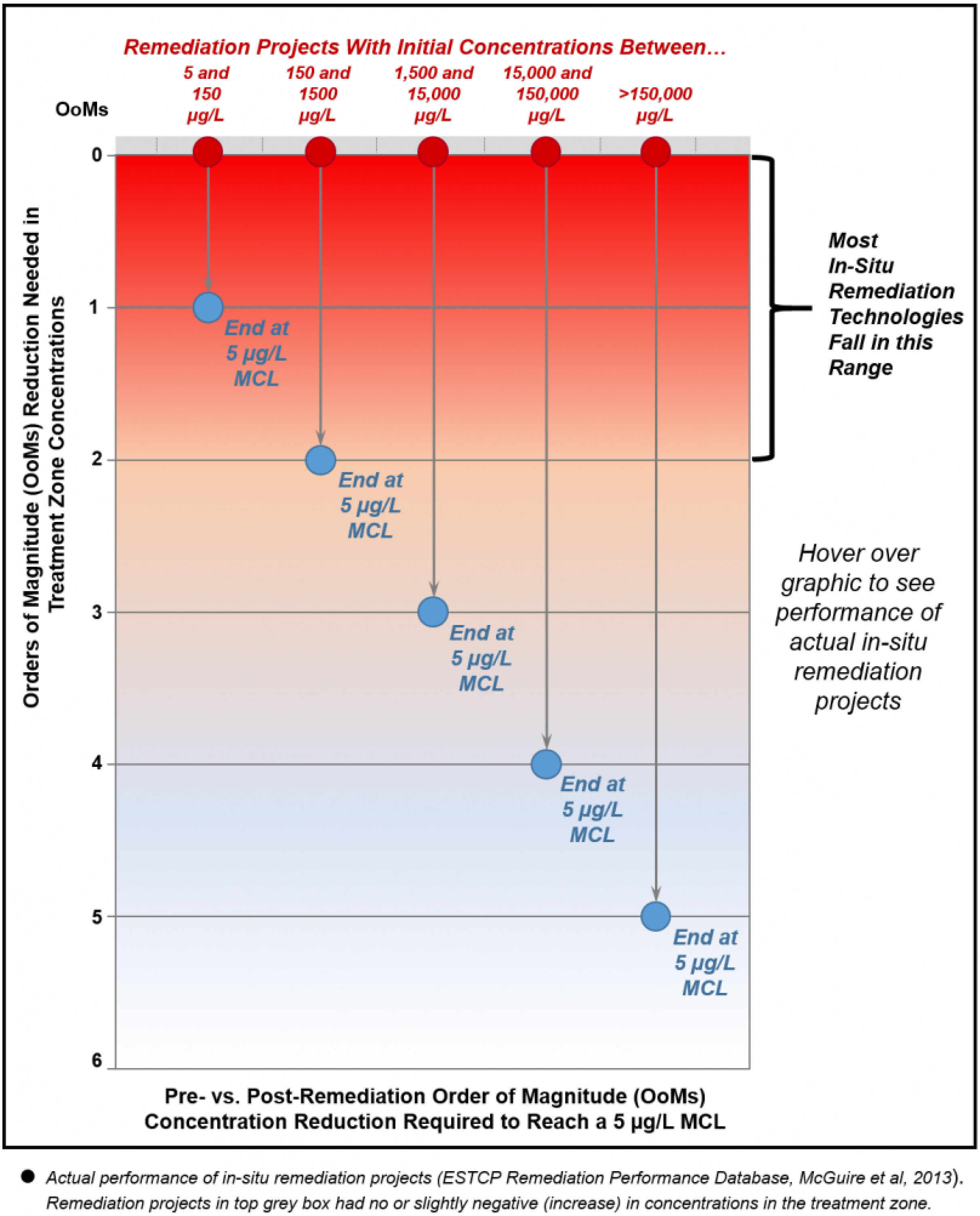

Figure 1-1. Well-implemented in situ remediation projects are likely to reduce source zone groundwater concentrations by about one to possibly two orders of magnitude (90%-99% reduction) from pretreatment levels. *Source:* Sale et al. 2008. Hover over graphic to see performance of actual in-situ remediation projects.

As a result, an environment management strategy for DNAPL and chlorinated solvent– contaminated sites should be developed on reliable data, be achievable, and be performance measurable. It must consider the limitation and uncertainty in our ability to fully characterize the subsurface and distribution of DNAPL and the removal, recovery, or treatment limitations of available remediation technologies. We can’t ask for, promise, or certainly achieve miracles; therefore, realistic expectations and time frames should be discussed and agreed to by the project managers, responsible parties, and regulators. To completely remediate a site, this process may occur several times to iteratively establish achievable and measurable remedial objectives.

1.1 Purpose of this Guidance

The purpose of this guidance is to provide users with a process for developing an integrated DNAPL site strategy (IDSS) for managing the challenges of remediating a chlorinated solvent– contaminated site. Because of site similarities, this strategy can apply to any chlorinated solvent– contaminated site regardless of the presence of DNAPL. This guidance summarizes the latest

thinking in five key areas, based on experience and lessons learned, to help all parties involved maximize the chances for successful outcomes related to chlorinated site management and cleanup:

- a **conceptual site model** (CSM) based on reliable characterization methods and an understanding of the subsurface conditions that control contaminant transport, reactivity, and distribution
- **remedial objectives** and performance metrics that are clear, concise, and measureable
- **treatment technologies** applied in sequence or in parallel designed to optimize performance and take advantage of potential synergistic effects
- **monitoring strategies** based on interim and final cleanup objectives, the selected treatment technology and approach, and remedial performance goals
- **reevaluating the strategy** repeatedly and even modifying the approach when objectives are not being met or when alternative methods offer similar or better outcomes at lower cost

This IDSS guidance is intended for regulators, remedial project managers, and remediation engineers responsible for remediating chlorinated solvent–contaminated sites. Because the subject matter is complex, this guidance is targeted towards experienced users; however, novices to the field will benefit from a thorough review of the text and accompanying references. The user of this guidance should be familiar with, and practiced on, the latest evolution of site characterization challenges; realistic planning of site restoration; evolving treatment techniques; and evaluating, monitoring, and interpreting mass transport in the subsurface aqueous and vapor phases. While this guidance addresses chlorinated solvent–contaminated sites, other types of sites (e.g., petroleum hydrocarbons or other mixed contaminants, etc.) can be addressed using the same site strategy.

1.2 The Need for an Integrated Strategy for Chlorinated-Solvent Sites

Since the enactment of federal and state environmental laws in the late 1970s and early 1980s (e.g., the Comprehensive Environmental Resource, Conservation, and Liability Act [CERCLA] and the Resource Conservation and Recovery Act [RCRA]), numerous chlorinated-solvent release sites have been assessed, and remediation begun, typically focused on groundwater restoration. However, by the mid-1990s, monitoring data had revealed that many remedies and operational decisions were based on an incomplete CSM and a misunderstanding of the performance of remedial technologies in a heterogeneous environment contaminated with chlorinated solvents. As a result, many attempts at source zone cleanup have removed contaminant mass and reduced mass discharge but have not achieved their desired end points. For instance, USEPA (1999) reported that fewer than 10% of pump-and-treat (P&T) sites had attained closure but 80% had attained containment. Though remediation technologies have improved over time, in many cases achieving regulatory closure remains difficult and costly, and sometimes impractical, particularly when the goal is to restore groundwater to drinking water quality standards throughout the source zone and plume in, for example, less than 30 years.

1.3 Involving Indian Tribe and Public Stakeholders

Given the financial, technical, and regulatory complexities inherent in the remediation process; uncertainties in the application of various technologies; and the poor history to date in DNAPL source zone remediation, it is highly recommended that effective communication be established with the stakeholders. In the context of this document, “stakeholders” consist of Indian tribes and public stakeholders, including citizens, community groups, advocacy organizations, and local officials. It is important to note that affected stakeholders are not necessarily limited to those in the immediate, local area around the site. For example, those who live downstream of a site may be affected even if they are not in the immediate vicinity. In the identification of affected tribes, it is necessary to consider that tribes may have treaties or other pacts with the federal government that grant them fishing, hunting, or access rights in places that are not necessarily near their present-day reservations. Furthermore, individual states and the Indian community recognize Indian tribes that are not necessarily recognized by the federal government.

Stakeholders generally show great interest in the contamination problem, remediation process, and effects that these have on human health and the environment. When planning remediation projects, the stakeholders should be fully informed of cleanup activities and potential consequences. A community relations plan should be prepared, and interested stakeholders should be involved, in the planning process even if it is from the emergency planning component. Many factors must be considered when determining the restoration project path, including the projected need for continuing surveillance and maintenance, institutional controls, engineered controls, local planning concerns, tribal government requirements, state regulators, and various stakeholders. In all cases, the process must have the goal of minimizing exposures to workers and the public, maximizing protection of the environment, and satisfying the concerns of the various stakeholders.

1.4 Is an IDSS a Site Closure Strategy?

This document is intended to promote the development of integrated strategies to improve cleanup and management of chlorinated-solvent sites and to maximize the chances for successful outcomes; however, this is not a site closure strategy. Not all chlorinated-solvent sites are alike; there is a range, from the relatively simple to extremely complex, depending on the size and depth of the source zone, presence or absence of DNAPL, hydrogeologic complexities, and age of the release.

On the technical side it has proven difficult to target and sufficiently treat the DNAPL within source zones in a realistic and predictable time frame. To achieve MCLs in DNAPL source zones, models, calibrated to remedial performance results, often predict cleanup time frames on the order of decades to centuries. But such predictions are highly uncertain, and our ability to measure meaningful progress toward such distant end goals is questionable. Furthermore, objectives that incorporate time frames of more than 20 years do not encourage accountability by the decision makers or take advantage of technology improvement, improved scientific understanding, and potential changes in the conditions of the site. In the end, objectives that require such long time frames can lose their relevance.

Consequently, attaining meaningful interim objectives that lead toward achieving closure standards, or alternative end points, may define success for many sites. For example, “success” could be defined in terms of achieving numeric cleanup standards everywhere throughout the source and plume, or it could be defined in terms of other interim or alternative objectives, such as the following:

- containing the source zone while achieving numeric cleanup standards in the downgradient plume
- transitioning to a passive remedy, such as monitored natural attenuation (MNA)
- achieving specific mass removal and/or mass discharge targets
- controlling human health or ecological exposures

IDSSs developed using this guidance provides a coherent strategy to improve the success of achieving site-specific objectives while optimizing remedial effectiveness, efficiency, and cost. An IDSS is not a silver bullet to achieve complete cleanup at any or all chlorinated-solvent sites. Rather, an IDSS can maximize the chances for successful outcomes through improvement of the CSM, development of SMART (specific, measurable, attainable, relevant, and time-bound—see Chapter 3) functional objectives, deployment of optimal treatment technologies and planned transitions, effective monitoring strategies, and strategic reevaluation.

1.5 When to Develop a Chlorinated Solvent–Contaminated Site Strategy

A strategy to reach a goal is certainly a good idea, and strategies are usually developed for most chlorinated-solvent sites. However, the core questions to ask when evaluating the performance of a chlorinated solvent–contaminated site strategy are as follows:

- How well is the current strategy working?

- If it is falling short in some regard, what else should be done?
- What technological improvements have become available that would work more efficiently?
- How can the CSM be improved?

An IDSS for a chlorinated solvent–contaminated site can be developed or updated at any point in the remedial process. Ideally, the strategy is created before any remediation has occurred and before much money has been spent. On the other hand, sites where remediation is already occurring (most common) can benefit from the development and/or update of the overall strategy.

1.6 Structure of the Document

Figure 1-2 both illustrates the process flow of IDSS development and represents the organization of this guidance. Each chapter uses small version of this flow diagram to help users track their progress in developing an IDSS. The five key areas of an IDSS, listed in Section 1.1, are represented in Chapters 2–6. Case studies (Appendix A) are used to highlight specific elements of each chapter. Even though no single case study can illustrate the use of an IDSS, Appendix B describes the development of an IDSS using an example based on real site characteristics. Chapter 6 describes a process to reevaluate a remedy and correct an underperforming remedy, transition to a different remedy, or improve the existing remedy. Not surprisingly, Chapter 6 is the point where most chlorinated-solvent site management teams begin, reflecting the fact that most teams have probably been managing their sites for a significant period and are now asking, “How are the current measures working, and what else might be done?”

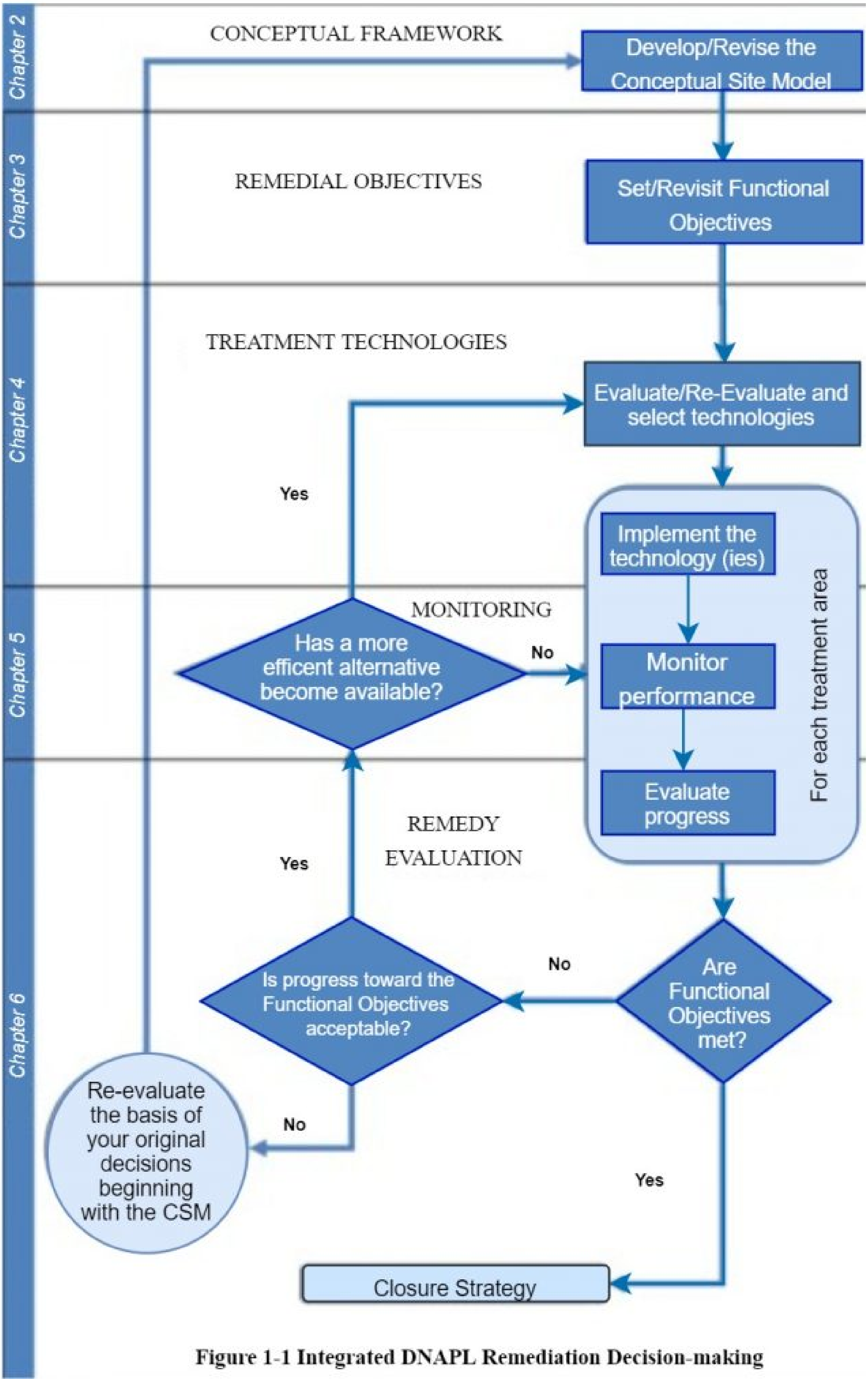

Figure 1-1 Integrated DNAPL Remediation Decision-making

Figure 1-2. Integrated DNAPL remediation decision making.