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Research article

# Remediation management of complex sites using an adaptive site management approach

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ABSTRACT

Complex sites require a disproportionate amount of resources for environmental remediation and long timeframes to achieve remediation objectives, due to their complex geologic conditions, hydrogeologic conditions, geochemical conditions, contaminant-related conditions, large scale of contamination, and/or non-technical challenges. A recent team of state and federal environmental regulators, federal agency representatives, industry experts, community stakeholders, and academia worked together as an Interstate Technology & Regulatory Council (ITRC) team to compile resources and create new guidance on the remediation management of complex sites. This article summarizes the ITRC team's recommended process for addressing complex sites through an adaptive site management approach. The team provided guidance for site managers and other stakeholders to evaluate site complexities and determine site remediation potential, i.e., whether an adaptive site management approach is warranted. Adaptive site management was described as a comprehensive, flexible approach to iteratively evaluate and adjust the remedial strategy in response to remedy performance. Key aspects of adaptive site management were described, including tools for revising and updating the conceptual site model (CSM), the importance of setting interim objectives to define short-term milestones on the journey to achieving site objectives, establishing a performance model and metrics to evaluate progress towards meeting interim objectives, and comparing actual with predicted progress during scheduled periodic evaluations, and establishing decision criteria for when and how to adapt/modify/revise the remedial strategy in response to remedy performance. Key findings will be published in an ITRC Technical and Regulatory guidance document in 2017 and free training webinars will be conducted. More information is available at www.itrc-web.org.


## 1. Introduction

At many sites, it is difficult to fully remediate environmental contamination within a reasonable amount of time using proven environmental remediation approaches due to complex, site-specific conditions. Sites may have large groundwater plumes, contaminated soils, surface water and/or sediments because of previous military or industrial activities. The term “complex site” was described by the National Research Council (NRC) as follows:

“Although progress has been made in remediating many hazardous waste sites, there remains a sizeable population of *complex sites* where restoration is likely not achievable in the next 50 to 100 years. Although there is no formal definition of complexity, most remediation professionals agree that attributes include areally extensive groundwater contamination, heterogeneous geology, large releases and/or source zones, multiple and/or recalcitrant contaminants, heterogeneous contaminant distribution in the subsurface, and long timeframes since releases occurred. Additional factors that contribute to complexity include restrictions on the physical placement or operation of remedial technologies and challenging expectations (e.g., regulatory requirements, cleanup goals, community expectations). The complexity of a site increases with the number of these characteristics present.” – NRC, 2013.

Complex sites often require long remediation time frames and a disproportionate share of cleanup budgets. In 2011, a study compiling data from Department of Defense (DoD) sites found that remedy completion would not be reached until at least 2022 at 588 groundwater sites (Vogel, 2015). Ten percent of these sites had

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costs to completion estimates ranging from $14.3 to $122.2 million. Thirty-one percent of the sites accounted for 80% of the total cost to completion (Vogel, 2015). In addition to economic impacts, complex sites also tend to consume large amounts of energy and other resources, emit more greenhouse gases, and generate more waste. There is significant potential to reduce the environmental footprint through considering green and sustainable remediation.

There are also economic benefits to the remediation of complex sites. One study (United States Environmental Protection Agency [USEPA], 2015) found that Brownfield remediation can increase nearby residential property values by 5.1–12.8 percent. Loss of surface water, groundwater and other natural resources is frequently a problem at complex sites. Municipalities, rural residents, Tribes and populations dependent upon natural resources for clean drinking water, recreational/subsistence hunting and fishing, and other recreational uses can be economically impacted by contamination. Remediation of public resources can restore public health, reduce stigma, improve property values, increase commerce, and allow for the continuation of cultural practices. More efficient and environmentally sustainable approaches to managing the remediation of complex sites are needed.

This article summarizes the content of a guidance document on the remediation management of complex sites that is currently being prepared by the Interstate Technical & Regulatory Council (ITRC, 2017). The guidance document provides an approach to manage remediation at complex sites, as well as tools, examples of site management elements, and detailed case studies.

## 2. Material and methods

Materials presented in this document are the product of the ITRC Remediation Management of Complex Sites team. ITRC teams develop guidance documents and training modules to reduce barriers to using innovative environmental technologies and approaches, broaden and deepen technical knowledge, and expedite quality regulatory decision-making while protecting human health and the environment. ITRC documents are written and reviewed by teams of volunteers from the private and public sectors nationwide, including state and federal environmental regulators, federal agency representatives, industry experts, community stakeholders, and academia. ITRC teams follow a consensus-based process to develop and iteratively improve guidance documents and training materials. The teams are led by regulators from state environmental agencies that facilitate the process of reaching consensus and manage document revisions.

ITRC's Remediation Management of Complex Sites team is still in the process of finalizing the draft Technical and Regulatory (TechReg) guidance document (ITRC, 2017). Results summarized in this document are draft and subject to change based on subsequent team review and revision, following ITRC's process. Readers should consult the ITRC website (www.itrcweb.org) for more detailed information and to download a copy of the final TechReg document (ITRC, 2017).

Prior to preparing the TechReg document, the ITRC team surveyed ITRC State and Tribal Points of Contact to gauge current state regulatory practices at complex sites. State and Tribal representatives were asked the following two questions:

1. Does your State/Tribal program allow the following as a primary means to meet remedial action objectives (RAOs)?
2. Does your State/Tribal program allow the following after the original selected remedy fails to reach the RAOs within the planned remedial timeframe?

Several methods of designating alternative points of compliance, contaminant management areas (i.e., areas subject to institutional controls, plume containment), criteria adjustment, schedule adjustment, technology adjustment, and other alternatives were then listed in a table and could be checked off by survey respondents. The term “RAOs” was used in the survey to encompass a broad range of State and Federal remediation program objectives, hereafter referred to as “site objectives”. ITRC received responses from 40 of the 50 states. Results are presented and discussed in Section 3.

To develop the TechReg document, team members attended semi-annual multi-day team meetings and monthly conference calls over a three-year period to discuss key concepts, hear from invited speakers on relevant topics, and discuss the purpose and content of the guidance document. Approximately 190 team members participated in the process. Team members volunteered to write and review draft sections of the document, discussed draft materials, and provided comments on other document sections. Team members responded to comments and revised draft work products accordingly. Results of this process are summarized in the team's TechReg document and in Section 3.

## 3. Results and discussion

Highlights from the ITRC team's TechReg document are presented below. Section 3.1 describes the overall recommended process for remediation management of complex sites, referred to as “adaptive site management”. Sections 3.2 through 3.7 provide more detail on key aspects of adaptive site management. Section 3.8 presents discussion that is relevant to stakeholder involvement at complex sites and Section 3.9 describes case studies of remediation management at complex sites.

### 3.1. Adaptive site management

The term “adaptive site management” refers to a comprehensive, flexible, and iterative process of remediation management that can be useful at complex sites. The concept of adaptive site management is to iteratively evaluate and adjust the strategy for remediation management in response to remedy performance. Because new knowledge is continually incorporated into the conceptual site model (CSM), both the CSM and the strategy for remediation management improve over time and remedial progress continues. Although any site may use the adaptive site management process, it is particularly well-suited for use at complex sites due to the significant uncertainty in predicting remedy performance. Complex sites may require more iterations of the adaptive site management process compared with simpler sites. The term “adaptive site management” was first coined by NRC (2003). USEPA has not used this terminology, but has described a similar process: a “step-wise groundwater completion strategy” (USEPA, 2014). The ITRC team's description of the adaptive site management process at complex sites is illustrated in Fig. 1.

The steps shown in Fig. 1 incorporate and refer to many best management practices, tools and technologies described in previous publications by USEPA, ITRC, DoD and others. More details on several aspects of the adaptive site management process are provided in Sections 3.2 through 3.7.

### 3.2. Complexity attributes

Complex sites must follow the same regulatory requirements and processes for remedy selection and implementation compared with simpler sites. Simpler sites can also use an adaptive site management approach. Therefore, the ITRC team did not think it was necessary to formally define the term “complex site”. The term

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