Ground-Water Monitoring Perspectives and Needs

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Introduction

A relatively new perspective for ground-water monitoring focuses on its use in confirming performance assessments (PA) of nuclear facility sites and facilities. The PA often includes numerical simulations of the site’s hydrogeologic system including anticipated features, events and processes (FEP) that may occur over long-time periods. The U.S. Nuclear Regulatory Commission (NRC) is funding research to develop an integrated ground-water monitoring strategy (IGWMS) to support the PA of nuclear waste and decommissioning sites. These PAs will support risk-informed decisions for ensuring the long-term safety of these sites.

The IGWMS will integrate monitoring with PA. IGWMS will provide practical guidance for reviewing NRC licensees’ ground-water monitoring programs. The objective is to provide monitoring data on the performance indicators (PI) (e.g., distributions of water content in the unsaturated zone, ground-water potential in the saturated zone, and radionuclide concentrations) of the hydrogeologic system behavior that are common to both site characterization and PA. Implementation of the IGWMS will provide data and analyses for evaluating the range of realistic alternative conceptual ground-water models and PIs, and for quantifying both parameter and model uncertainties.

In addition to the conventional monitoring needs of identifying and mapping contaminant plumes, the IGWMS goals are to:

- Identify the presence or potential for preferential transport pathways;
- Assess the effectiveness of contaminant isolation systems;
- Identify and support alternative conceptual flow and transport models; and
- Inform the decision-makers through communication of the monitored PIs using data management, analysis and visualization techniques.

Generic Ground-Water Monitoring Needs

The generic ground-water monitoring needs that will be identified in the IGWMS cover a wide range of site conditions. The IGWMS will need to be robust enough to cover three broad categories of sites:

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\textsuperscript{1} The NRC defines ground water as all subsurface water within both the unsaturated and saturated zones.
• New sites or sites with no evidence of releases that may have the need for baseline, pre-operational and operational monitoring;
• Sites with early indication of possible failures or potential release that would have the need for additional detection and remediation monitoring; and
• Sites with releases and identifiable plumes that would have the need for detection, remediation, and post-remediation monitoring.

For new sites or those with no evidence of releases, the monitoring would focus on performance indicators that would establish baseline conditions and possibly demonstrate deviation from design performance that could affect contaminant transport.

For sites with early indications of possible failure or potential release, the monitoring would develop a database for identifying and quantifying the transport mechanisms (e.g., those events and processes in the unsaturated and saturated zones contributing to radionuclide transport). Monitoring, particularly in the unsaturated zone, can assess the effectiveness of contaminant isolation systems, and detect precursors to engineered barrier failure.

For decommissioning sites with existing ground-water contaminant plumes, the monitoring program would characterize the contaminant plume’s extent and behavior through time. EPA has developed guidelines for monitoring ground-water contaminant plumes (EPA, 2004). The IGWMS will reference these and other established guidelines where appropriate. The monitoring will provide valuable information to develop and assess remediation approaches such as in-situ bioremediation and monitored natural attenuation.

An important consideration is that monitoring is highly site-specific, and will need to support NRC acceptance criteria. For some sites, acceptance criteria are based on radionuclide concentration levels (e.g., in-situ leach uranium recovery facilities) while for other sites acceptance criteria are based on calculated doses (e.g., decommissioned sites) depending on the relevant regulatory criteria. For all sites, the monitoring strategy would focus on identifying preferential transport pathways (e.g., presence of heterogeneities and perched-ground-water systems). Similarly for all sites, the monitoring strategy needs to identify precursors to system failures and releases that would be defined using monitored PIs.

**Technical Considerations**

The IGWMS will be designed to couple monitoring to site characterization and facility PA using PIs. These PIs can be monitored and analyzed to confirm system performance in order to support decision-making. Using this new perspective of monitoring PIs would facilitate formal statistical analyses (e.g., Bayesian updating method) to update the PA. The Bayesian updating method is currently being tested to assess uncertainty in hydrogeologic conceptual models (Neuman and Wierenga, 2003), and could be coupled to the IGWMS.

Another new aspect of the IGWMS is the use of the monitored PIs to identify alternative conceptual flow and transport models. For example, will the subsurface flow and transport occur throughout the porous media, or predominately through fractures and other
heterogeneities? As shown in Figure 1, different conceptual models to represent flow in fractured media could be chosen that result in different relative permeability curves.

The conceptual model(s) can also be confirmed by the IGWMS since it is an integral part of the PA. Because each site has its own unique set of FEP, the IGWMS will focus on the design of monitoring system to detect both current conditions and changes in the system (e.g., behavior relevant to radionuclide leaching and transport). The IGWMS will consider these site-specific FEPs to determine the appropriate sensors and methods for monitoring the PIs relevant to the identified conceptual models.

An example of these FEPs is shown in Figure 2. For such a complex site, the scale, geometry, and environmental interfaces of the engineered systems may also affect the flow and transport paths, and will need to be factored into the IGWMS. In this example, the presence and extent of perched water systems may be caused, in part by engineered system performance failure, that could significantly affect radionuclide transport, and would need to be considered in the monitoring design. The IGWMS needs to be adaptable and robust to
accommodate various performance confirmation monitoring needs involving remediation options, and other short-term and long-term monitoring needs.

Figure 2. Conceptual model of a complex site showing various features, events and processes which may affect radionuclide transport (after Ward and others, 1997).

For decommissioning sites, the use of unsaturated zone monitoring strategies developed by Young and others, 1999b are being examined for incorporation in the IGWMS. The technical considerations here include choosing the appropriate sensor [e.g., solution samplers] and method [e.g., electroresistivity borehole tomography (ERT)] for the specified PI. The decisions for “where, when and how” to monitor evolves from the PI (i.e., “what” to monitor) and the conceptual model (i.e., FEP controlling flow and radionuclide transport). Emphasis is on unsaturated zone monitoring since the radioactive source is often above the regional water table where the dynamic events and processes that leach, mobilize and transport the contaminants originate. Methods, techniques and sensors described by: Everett and others, 1984; Young and others, 1999a,b; Gee and others, 2001; Timlin and others, 2003; and more recently EPA, 2004a,b; will be reviewed and cited where appropriate.
Implementation

The IGWMS is being developed to provide practical guidance useful for NRC staff evaluations of NRC licensees’ ground-water monitoring programs. The guidance is to include information and techniques for identifying risk-significant PIs (e.g., radionuclide concentrations) to be monitored. The guidance will be useful to demonstrate the connection between the monitored PIs and PA. For assessing long-term performance (e.g., out to 1,000 years), the guidance will demonstrate the use of monitoring data as input to PA models (i.e., parameter estimation, model calibration and uncertainty analyses).

IGWMS will be tested using real-time monitoring datasets. The test cases to be selected for this testing need to include monitoring information on dynamic processes in both the unsaturated and saturated zones relevant to radionuclide transport. The selection should also consider sites with a range of alternative conceptual flow and transport models and related PIs.

Conclusions

The development and testing of a systematic, robust and integrated ground-water monitoring strategy (IGWMS) should fulfill the generic needs and technical considerations mentioned. The IGWMS will be tested over a range of hydrogeologic FEPs and PIs using site-specific monitoring datasets. The IGWMS will provide practical information for:

- Understanding monitoring needs to verify PA;
- Identifying conceptual models related to initiating events and processes (e.g., source-term release, episodic recharge events);
- Supporting PA models of long-term performance (e.g., estimating parameter and boundary conditions and assessing uncertainties);
- Assessing the effectiveness of engineered systems and remediation approaches; and
- Informing the decision makers through communication of the monitored PIs using data management, analysis and visualization techniques.

Following testing and technology transfer seminars to the NRC staff, the IGWMS is anticipated to be available in the fall of 2006.

References


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