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Practical Applications of Groundwater Modeling in Contaminated Site Investigation and Remediation

Toskos T.[1,*]

[1] Woodard & Curran, New Jersey, USA

*corresponding author:
e-mail: theodoros.toskos@gmail.com

Abstract Modeling is a very useful tool in the investigation and remediation of contaminated sites, that is generally misunderstood and underutilized. Often, modeling is perceived as requiring protracted and expensive efforts, beyond the means of most projects. However, developing a clear set of objectives and understanding the limitations of each modeling effort enables us to develop the information that needed and to obtain regulatory closure. We are providing examples of how the application of these principles allows to obtain valuable results expending only modest effort and cost.

Keywords: modeling, contamination, investigation

1. Introduction

Groundwater flow models provide a mathematical representation of groundwater movement through saturated media (sediment or rock). Models allow us to develop a consistent representation of aquifer properties, estimate and predict flows and aquifer characteristics when direct observations are not available, analyze and test hypotheses for site hydrogeology and constrain and predict the behavior of remediation systems. Use of modeling in contaminated site investigation and remediation is not as wide and common as one might expect, given the benefits of the quantitative simulation. To a good extend, this is due to the perception that modeling is an overly specialized, time consuming and expensive task that often yields ambiguous results. This does not have to be so. As with all other project activities, modeling must be approached in a deliberate and organized fashion with specific objectives and clear expectations, to obtain the desired outcome.

2. Data Quality Objectives

Data Quality Objectives (DQOs) is a logical process that guides the project team to plan for the efficient acquisition of environmental data (USEPA, 2006). The process is widely utilized in the planning and execution of sampling programs, but it is applicable in any situation when data must be generated and assessed. We have applied this process to set up modeling efforts to support specific aspects of contaminated site investigation and remediation activities. The typical DQO setting steps are:

- Define the nature of the problem.
- Define the site conceptual model.
- Define the information needed to solve the problem.
- Define the type of data needed.
- Define how the data will be used to draw conclusions.
- Define acceptable quantitative criteria on the quality and quantity of data to be collected.
- Define a data collection design to generate acceptable data.

In many cases the need to model a specific aspect of the site hydrogeologic system does not come until the investigation and remediation has advanced to a stage where complex issues arise, and simpler methods of analysis cannot provide the needed answers. Because of the stage and timing of these projects, additional data collection and prolonged data analysis may no longer be feasible or desirable. The DQO setting process allows to effectively manage these constrains and be able to utilize modeling to obtain the information necessary.

3. Problem Formulation and Goal Setting

In most complex contaminated site investigation and remedial actions, conclusions and recommendations are based on combining information from various sources and activities. The term “multiple lines of evidence” is often used to describe this approach. Mathematical modeling can be one of these “lines of evidence.” Therefore, the investigator must determine which question the model will address and what evidence it will provide towards answering the question.

As outlined in the DQO process, above, the first step is to define the problem and the question that must be answered. The problem definition needs to be as specific as possible. For example, “can the contamination detected at the site be migrating from off-site under the influence of pumping wells” sets up a testable hypothesis that will provide specific information for site characterization. The next step is to define the data needed to construct and execute the model. In many cases models will be constructed using existing data. It is critical to review and understand the limitations of any such existing data set, as it will define the capabilities of the model and the expectations for an outcome. The outcome of this analysis must be compared to what is needed to construct the line of evidence we are hoping to arrive at. This is a critical step in the process. If the investigator requires high-resolution information but the dataset can only support a generalized analysis, the modeling should be abandoned, unless it will be possible to obtain additional needed data for inclusion in the model. Understanding and clearly stating the limitations of the model and comparing those to the type of answer needed for the task at hand, will ensure that the modeling output will be one of the necessary lines of evidence.

4. Case Examples

Groundwater sampling at a former industrial site detected the presence of chlorinated hydrocarbons. Historical operations were well documented, and the detection of chlorinated hydrocarbons was not justified. Off-site presence of potential source areas and significant pumping was documented in regulatory files. Site investigations had identified the presence of faults. This information was synthesized in a site conceptual model that postulated the off-site pumping well causing contaminated groundwater from the neighboring site to migrate through the site, via the observed fault zones. To test whether this hypothesis was, in fact, geologically feasible, we decided to model the system.

We defined the problem to be solved as “can the off-site pumping well capture the neighboring facility’s plume and cause it to migrate to our site though the mapped fault zone.” Given the stage of the site investigation and the size of the area in question, only existing data, from literature and previous investigations, were available for use. This implied that the model output would be generalized, and replication of site data (such as matching observed groundwater elevations) would likely not be possible. Under the circumstances it was decided that a generalized match of the geometry (e.g., relative changes in water levels, general matching of the shape of observed groundwater elevation contours) would be the targeted outcome, and the model output would be only one line of evidence in our analysis. Having defined the question we needed to answer, and the limitations of the model output, we completed the modeling with a modest effort and obtained information that validated our conceptual model and became one of many lines of evidence to support our interpretation of site conditions.

Conversely, a high-resolution output was required for a site where groundwater flow direction was opposite to what would be expected by regional hydrogeologic setting, and there were concerns that the site investigation may had not identify a key flow pathway.

We defined the problem to be solved as “Can the observed groundwater flow conditions be replicated, based on hydrogeologic setting and measurements, and can we demonstrate that there are no gaps in our understanding of the site.” The objective was to create an exact mathematical replica, that accurately matches the observed conditions. An extensive network of wells was present at the site, the site stratigraphy was well established, and extensive information about the regional geology, including detailed stratigraphic maps, was available. All this information was included in the mathematical model, which was calibrated to the site data and we demonstrated that the counterintuitive interpretation of the site hydrogeology was correct. We were also able to demonstrate that there was no unaccounted flow component. By setting up a clearly defined question and knowing the capabilities of the model, we completed the required work in a short period of time at a modest cost.

5. Discussion and Conclusions

When discussing modeling, we tend to think of substantial 3D simulations that require complex software and specialized training to operate. As environmental professionals we often need to develop semi-quantitative estimates of contaminant migration distances, effects of pumping, etc. This information is often a critical aid in our decision-making process. Spreadsheet models provide cost-effective way to estimate plume migration and assess remedial options. There are numerous such application that are available free of charge, have been validated and are universally acceptable. The DQO processes should be used to guide that successful deployment of these applications.

The targeted use of mathematical modeling in contaminated site investigation and remediation is a powerful tool for the investigator. A structured and disciplined approach must be followed to clearly define the question that must be answered and the limitation of any such answer. This approach minimized the effort expended, while maximized the usability and regulatory acceptance of the outcome.

References

USEPA (2006) Guidance on Systematic Planning Using the Data Quality Objectives Process. EPA/240/B-06/001