Designation: D6025 – 96 (Reapproved 2008)

Standard Guide for Developing and Evaluating Groundwater Modeling Codes[1]

This standard is issued under the fixed designation D6025; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers a systematic approach to the development, testing, evaluation, and documentation of groundwater modeling codes. The procedures presented constitute the quality assurance framework for a groundwater modeling code. They include code review, testing, and evaluation using quantitative and qualitative measures. This guide applies to both the initial development and the subsequent maintenance and updating of groundwater modeling codes.

1.2 When the development of a groundwater modeling code is initiated, procedures are formulated to ensure that the final product conforms with the design objectives and specifications and that it correctly performs the incorporated functions. These procedures cover the formulation and evaluation of the code's theoretical foundation and code design criteria, the application of coding standards and practices, and the establishment of the code's credentials through review and systematic testing of its functional design and through evaluation of its performance characteristics.

1.3 The code's functionality needs to be defined in sufficient detail for potential users to assess the code's utility as well as to enable the code developers to design a meaningful code testing strategy. Comprehensive testing of a code's functionality and performance is accomplished through a variety of test methods. Determining the importance of the tested functions and the ratio of tested versus non-tested functions provides an indication of the completeness of the testing.

1.4 Groundwater modeling codes are subject to the software life cycle concept that consists of a design phase, a development phase, and an operational phase. During the operational phase the software is maintained, evaluated regularly, and changed as additional requirements are identified. Therefore, quality assurance procedures should not only be established for software design, programming, testing, and use, but also for code maintenance and updating.

1.5 Quality assurance in the development of groundwater modeling codes cannot guarantee acceptable quality of the code or a groundwater modeling study in which the code has been used. However, adequate quality assurance can provide safeguards against the use in a modeling study of faulty codes or incorrect theoretical considerations and assumptions. Furthermore, there is no way to guarantee that modeling-based advice is entirely correct, nor that the groundwater model used in the preparation of the advice (or any scientific model or theory, for that matter) can ever be proven to be entirely correct. Rather, a model can only be invalidated by disagreement of its predictions with independently derived observations of the studied system because of incorrect application of the selected code, the selection of an inappropriate code, the use of an inadequately tested code, or invalidity of or errors in the underlying theoretical framework.

1.6 This guide is one of a series of guides on groundwater modeling codes and their applications, such as Guides D5447, D5490, D5611, D5609, D5610, and D5718. Other standards have been prepared on environmental modeling, such as Practice E978.

1.7 Complete adherence to this guide may not always be feasible. If this guide is not integrally followed, the elements of noncompliance should be clearly identified and the reasons for the partial compliance should be given. For example, partial compliance might result from inadequacy of existing field techniques for measuring relevant model parameters, specifically in complex systems.

1.8 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this*

[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

Current edition approved Sept. 15, 2008. Published November 2008. Originally approved in 1996. Last previous edition approved in 1996 as D6025 – 96 (2002). DOI: 10.1520/D6025-96R08.

document means only that the document has been approved through the ASTM consensus process.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D5447 Guide for Application of a Groundwater Flow Model to a Site-Specific Problem

D5490 Guide for Comparing Groundwater Flow Model Simulations to Site-Specific Information

D5609 Guide for Defining Boundary Conditions in Groundwater Flow Modeling

D5610 Guide for Defining Initial Conditions in Groundwater Flow Modeling

D5611 Guide for Conducting a Sensitivity Analysis for a Groundwater Flow Model Application

D5718 Guide for Documenting a Groundwater Flow Model Application

E978 Practice for Evaluating Mathematical Models for the Environmental Fate of Chemicals (Withdrawn 2002)[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *code verification, n— in groundwater modeling*, the process of demonstrating the consistency, completeness, correctness, and accuracy of a groundwater modeling code with respect to its design criteria by evaluating the functionality and operational characteristics of the code and testing embedded algorithms and internal data transfers through execution of problems for which independent benchmarks are available (**1**).[4]

3.1.1.1 *Discussion*—In software engineering, verification is the process of demonstrating consistency, completeness, and correctness of the software (**2**). Practice E978 defines verification as "...the examination of the numerical technique in the computer code to ascertain that it truly represents the conceptual model and that there are no inherent problems with obtaining a solution." In this guide, the term code verification is used. The objective of the code verification process is threefold: (*1*) to check the correctness of the program logic and the computational accuracy of the algorithms used to solve the governing equations; (*2*) to ensure that the computer code is fully operational (no programming errors); and (*3*) to evaluate the performance of the code with respect to all of its designed and inherent functions (**1**).

A code can be considered "verified" when all its functions and operational characteristics have been tested and have met specific performance criteria, established at the beginning of the verification procedure. Considering a code verified does not imply that a groundwater model application constructed with the code is verified.

NOTE 1—In groundwater modeling, the term "validation" is sometimes used to describe the process of determining how well a groundwater modeling code's theoretical foundation and computer implementation describe actual system behavior in terms of the degree of correlation between calculated and independently observed cause-and-effect responses of the reference groundwater system for which the code has been developed (**1,3**). This process is also referred to as field demonstration, field comparison, or extended verification (**4**).

NOTE 2—Validation as described in Note 1 is by nature a subjective and open-ended process. As there is no practical way to determine that a groundwater modeling code correctly represents the reference system, the code can never be considered "validated." Therefore, this guide does not endorse the use of the term validation in the context of groundwater modeling (**1,3,4**).

3.1.2 *computer code (computer program), n—* the assembly of numerical techniques, bookkeeping, and control language that represents a model from acceptance of input data and instructions to delivery of output.

3.1.3 *functionality, n— of a groundwater modeling code*, the set of functions and features the code offers the user in terms of model framework geometry, simulated processes, boundary conditions, and analytical and operational capabilities.

3.1.4 *groundwater model application, n—* a nonunique, simplified mathematical description of one or more subsurface components of a local or regional hydrologic system, coded in a computer programing language, together with a quantification of the simulated system in the form of framework geometry, boundary conditions, system and process parameters, and system stresses.

3.1.4.1 *Discussion*—As defined in 3.1.4, a groundwater model application is a representation of an actual hydrologic system; it should not be confused with the generic computer code used in formulating the groundwater model. This guide concerns only the development, testing, and documentation of generic simulation computer codes, not groundwater model applications.

3.1.5 *groundwater modeling, n*—the process of developing groundwater models.

3.1.6 *groundwater modeling code, n*—the nonparametrized computer code used in groundwater modeling to represent a nonunique, simplified mathematical description of the physical framework, geometry, active processes, and boundary conditions present in a reference subsurface hydrologic system.

3.1.6.1 *Discussion*—The term "nonparameterized computer code" refers to a generalized computer program in which values of parameters can be specified by the user.

3.1.7 *quality assurance (QA), n*—in the development of a groundwater modeling code, the procedural and operational framework put in place by the organization managing the code development project, to ensure technically and scientifically adequate execution of all project tasks, and to ensure that the resulting software product is functional and reliable.

3.2 For definitions of other terms used in this guide, see Terminology D653.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.