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Standard Guide for
Defining Boundary Conditions in Groundwater Flow Modeling[1]

This standard is issued under the fixed designation D5609; 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.

ε^1 NOTE—Reapproved with editorial changes in September 2015.

1. Scope*

1.1 This guide covers the specification of appropriate boundary conditions that are to be considered part of conceptualizing and modeling groundwater systems. This guide describes techniques that can be used in defining boundary conditions and their appropriate application for modeling saturated groundwater flow model simulations.

1.2 This guide is one of a series of standards on groundwater flow model applications. Defining boundary conditions is a step in the design and construction of a model that is treated generally in Guide D5447.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 *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 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

3. Terminology

3.1 For common definitions of terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aquifer, confined*—an aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer.

3.2.2 *boundary*—geometrical configuration of the surface enclosing the model domain.

3.2.3 *boundary condition*—a mathematical expression of the state of the physical system that constrains the equations of the mathematical model.

3.2.4 *conceptual model*—a simplified representation of the hydrogeologic setting and the response of the flow system to stress.

3.2.5 *flux*—the volume of fluid crossing a unit cross-sectional surface area per unit time.

3.2.6 *groundwater flow model*—an application of a mathematical model to the solution of a groundwater flow problem.

3.2.7 *hydraulic conductivity—(field aquifer tests)*, the volume of water at the existing kinematic viscosity that will move in a unit time under unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

3.2.8 *hydrologic condition*—a set of groundwater inflows or outflows, boundary conditions, and hydraulic properties that cause potentiometric heads to adopt a distinct pattern.

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[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.

***A Summary of Changes section appears at the end of this standard**

3.2.9 *simulation*—one complete execution of the computer program, including input and output.

3.2.10 *transmissivity*—the volume of water at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit width of the aquifer.

3.2.11 *unconfined aquifer*—an aquifer that has a water table.

4. Significance and Use

4.1 Accurate definition of boundary conditions is an important part of conceptualizing and modeling groundwater flow systems. This guide describes the properties of the most common boundary conditions encountered in groundwater systems and discusses major aspects of their definition and application in groundwater models. It also discusses the significance and specification of boundary conditions for some field situations and some common errors in specifying boundary conditions in groundwater models.

5. Types of Boundaries

5.1 The flow of groundwater is described in the general case by partial differential equations. Quantitative modeling of a groundwater system entails the solution of those equations subject to site-specific boundary conditions.

5.2 *Types of Modeled Boundary Conditions*—Flow model boundary conditions can be classified as specified head or Dirichlet, specified flux or Neumann, a combination of specified head and flux, or Cauchy, free surface boundary, and seepage-face. Each of these types of boundaries and some of their variations are discussed below.

5.2.1 *Specified Head, or Dirichlet, Boundary Type*—A specified head boundary is one in which the head can be specified as a function of position and time over a part of the boundary surface of the groundwater system. A boundary of specified head may be the general type of specified head boundary in which the head may vary with time or position over the surface of the boundary, or both, or the constant-head boundary in which the head is constant in time, but head may differ in position, over the surface of the boundary. These two types of specified head boundaries are discussed below.

5.2.1.1 *General Specified-Head Boundary*—The general type of specified-head boundary condition occurs wherever head can be specified as a function of position and time over a part of the boundary surface of a groundwater system. An example of the simplest type might be an aquifer that is exposed along the bottom of a large stream whose stage is independent of groundwater seepage. As one moves upstream or downstream, the head changes in relation to the slope of the stream channel and the head varies with time as a function of stream flow. Heads along the stream bed are specified according to circumstances external to the groundwater system and maintain these specified values throughout the problem solution, regardless of changes within the groundwater system.

5.2.1.2 *Constant-Head Boundary*—A constant head boundary is boundary in which the aquifer system coincides with a surface of unchanging head through time. An example is an aquifer that is bordered by a lake in which the surface-water stage is constant over all points of the boundary in time and position or an aquifer that is bordered by a stream of constant flow that is unchanging in head with time but differs in head with position.

5.2.2 *Specified Flux or Neumann Boundary Type*—A specified flux boundary is one for which the flux across the boundary surface can be specified as a function of position and time. In the simplest type of specified-flux boundary, the flux across a given part of the boundary surface is considered uniform in space and constant with time. In a more general case, the flux might be constant with time but specified as a function of position. In the most general case, flux is specified as a function of time as well as position. In all cases of specified flux boundaries, the flux is specified according to circumstances external to the groundwater flow system and the specified flux values are maintained throughout the problem solution regardless of changes within the groundwater flow system.

5.2.2.1 *No Flow or Streamline Boundary*—The no-flow or streamline boundary is a special case of the specified flux boundary. A streamline is a curve that is tangent to the flow-velocity vector at every point along its length; thus no flow crosses a streamline. An example of a no-flow boundary is an impermeable boundary. Natural earth materials are never impermeable. However, they may sometimes be regarded as effectively impermeable for modeling purposes if the hydraulic conductivities of the adjacent materials differ by orders of magnitude. Groundwater divides are normal to streamlines and are also no-flow boundaries. However, the groundwater divide does not intrinsically correspond to physical or hydraulic properties of the aquifer. The position of a groundwater divide is a function of the response of the aquifer system to hydrologic conditions and may be subject to change with changing conditions. The use of groundwater divides as model boundaries may produce invalid results.

5.2.3 *Head Dependent Flux, or Cauchy Type*—In some situations, flux across a part of the boundary surface changes in response to changes in head within the aquifer adjacent to the boundary. In these situations, the flux is a specified function of that head and varies during problem solution as the head varies.

NOTE 1—An example of this type of boundary is the upper surface of an aquifer overlain by a confining bed that is in turn overlain by a body of surface water. In this example, as in most head-dependent boundary situations, a practical limit exists beyond which changes in head cease to cause a change in flux. In this example, the limit will be reached where the head within the aquifer falls below the top of the aquifer so that the aquifer is no longer confined at that point, but is under an unconfined or water-table condition, while the confining bed above remains saturated. Under these conditions, the bottom of the confining bed becomes locally a seepage face. Thus as the head in the aquifer is drawn down further, the hydraulic gradient does not increase and the flux through the confining bed remains constant. In this hypothetical case, the flux through the confining bed increases linearly as the head in the aquifer declines until the head reaches the level of the base of the confining bed after which the flux remains constant. Another example of a head dependent boundary with a similar behavior is evapotranspiration from the water table, where the flux from the water table is often modeled as decreasing linearly with depth to water and becomes zero where the water table reaches some specified "cutoff" depth.

5.2.4 *Free-Surface Boundary Type*—A free-surface boundary is a moveable boundary where the head is equal to the elevation of the boundary. The most common free-surface