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70-19

Estimation of Aquifer Hydraulic Properties by Inverse Numerical Modeling of Aquifer Pumping Tests

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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PREFACE

This is a standard guideline for estimating the hydraulic properties of a groundwater system by inverse numerical modeling of aquifer pumping tests. This standard is applicable to situations where inverse methods based on analytical solutions for aquifer response to pumping are not applicable, which might occur when the pumping rate is time dependent, the hydrostratigraphy of the groundwater system is complex, or boundary conditions are present that influence aquifer response. Guidance is provided on using a numerical groundwater flow model to simulate an aquifer pumping test and estimate aquifer hydraulic properties by matching the simulated aquifer response in both space and time to observations of head or water level.

The methodology is based on minimizing the residual error between observed and simulated heads by adjusting (calibrating) values of the pertinent aquifer hydraulic properties (e.g., transmissivity, storativity, and leakance) such that there is a good match between the observed and simulated values. This match may be accomplished manually by trial and error; alternatively, automated optimization or nonlinear least squares regression techniques can be used to solve the inverse problem. The resulting set of aquifer hydraulic property values are then considered to be representative of the aquifer volume influenced by the aquifer pumping test. These aquifer hydraulic properties derived from this procedure may serve as the basis of predictive simulations of groundwater flow and solute transport under a different set of hydrologic stresses, or to assist in characterizing the statistical and geostatistical properties of aquifer hydraulic conductivity.

This standard represents the consensus of the Standards Committee on Fitting of Hydraulic Conductivity Using Statistical Spatial Estimation (called KSTAT) of the Standards Development Council (SDC) of the Environmental and Water Resources Institute (EWRI) of ASCE. This standard guideline is the fifth in a series of standards that seeks to enhance the probabilistic and empirical characterization and understanding of the saturated hydraulic conductivity (K_{sat}), a key groundwater parameter. The KSTAT Standards Committee has published four companion standard guidelines: ASCE/EWRI Standard 50-08 (ASCE 2008a), ASCE/EWRI Standard 51-08 (ASCE 2008b), ASCE/EWRI Standard 54-10 (ASCE 2010), and ASCE/EWRI Standard 65-17 (ASCE 2017). Standard 50-08 addresses the optimal fitting of saturated hydraulic conductivity (K_{sat}) with skewed probability density functions (PDFs). Standard 51-08 deals with the estimation of the effective saturated hydraulic conductivity, a parameter that relates the average specific discharge to the average hydraulic gradient. Standard 54-10 presents a methodology for the geostatistical interpolation and block averaging of K_{sat} in statistically homogeneous and isotropic aquifers. Standard 65-17 provides the means for calculating the saturated hydraulic conductivity of fine-grained soils based on stress–strain data obtained from standard consolidation tests.

The formulas in this standard require that all their values be expressed in both Système International (SI) units and the customary system of units in the United States. These are presented with customary units first, with SI units following in parentheses. The example applications included in this standard employ US customary units and SI units. Dimensions and quantities expressed in SI units are followed by conversion to US customary units in parentheses. Conversely, dimensions and quantities expressed in US customary units are followed by conversion to SI units in parenthesis.

ASCE does not endorse commercial spreadsheets, numerical software, or testing methods produced by other organizations cited in this standard. Any such products are cited to illustrate possible ways of carrying out calculations and conducting experimental tests that are cited in this standard guideline. It is left to the users' discretion to choose and verify the accuracy of whichever computational technique or testing method they apply to implement this standard's methodology.

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CHAPTER 1
INTRODUCTION

1.1 SCOPE

This standard is for estimating the hydraulic properties of a groundwater system by inverse numerical modeling of aquifer pumping tests. Guidance is provided on using a numerical groundwater flow model to simulate an aquifer pumping test (APT) and estimate aquifer hydraulic properties by matching the simulated aquifer response in space and time to observations of hydraulic head (henceforth referred to as *head*) or water level. The methodology is based on minimizing the residual error between observed and simulated heads by adjusting (calibrating) values of the pertinent aquifer hydraulic properties (e.g., transmissivity, storativity, and leakance) such that there is a good match between the observed and simulated values. This match may be accomplished manually by trial and error; alternatively, automated optimization or nonlinear least squares regression techniques can be used to solve the inverse problem. The resulting set of aquifer hydraulic property values are then considered to be representative of the aquifer volume influenced by the APT. The aquifer hydraulic properties derived from this procedure may serve as the basis of predictive simulations of groundwater flow and solute transport under a different set of hydrologic stresses, or they may be used to assist in characterizing the statistical (ASCE 2008a, b) and geostatistical (ASCE 2010) properties of aquifer hydraulic conductivity.

1.2 DEFINITIONS AND SYMBOLS

Definitions

Analytical model: In groundwater modeling, a model that is based on the closed-form, analytical solution to the governing equations of the applicable problem.

Aquiclude: A geologic formation that may contain water but is incapable of transmitting significant quantities under ordinary field conditions.

Aquifer: A geologic formation, or a group of formations, that (i) contains water and (ii) permits significant amounts of water to move through it under ordinary field conditions.

Aquifer pumping test (APT): A controlled field experiment used to estimate hydraulic properties of aquifer systems conducted by stressing the aquifer through constant pumping and observing the aquifer's response (drawdown) in observation wells or piezometers.

Aquitard: A hydrogeological unit that is permeable enough to transmit water in significant quantities when viewed over large areas and long periods, but its hydraulic conductivity is not sufficient to justify production wells being placed in it.

Calibration: The process of refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the groundwater system.

Calibration targets: Measured, observed, calculated, or estimated hydraulic heads or groundwater flow rates that a model must reproduce, at least approximately, to be considered calibrated.

Conceptual model: An interpretation or working description of the characteristics and dynamics of the physical system.

Confined aquifer: An aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer.

Confining bed: A hydrogeologic unit of less permeability bounding one or more aquifers.

Drawdown: Vertical distance the static head is lowered caused by the removal of groundwater.

Groundwater flow model: An application of a mathematical model to represent a site-specific groundwater flow system.

Groundwater modeling code: The nonparameterized computer code used in groundwater modeling to represent a nonunique, simplified mathematical description of the physical framework, geometry, active processes, boundary conditions, and initial conditions present in a reference subsurface hydrologic system.

Hydraulic head (head): The height above a standard datum of the surface of a column of water that can be supported by the hydraulic pressure at a given point in a groundwater system.

Hydraulic properties: Properties of soil and rock that govern the transmission (e.g., hydraulic conductivity, transmissivity, and leakance) and storage (e.g., specific storage, storativity, and specific yield) of water.

Hydrogeologic unit: Any soil or rock unit or zone which by virtue of its porosity or permeability, or lack thereof, has a distinct influence on the storage or movement of groundwater.

Inverse method: Solving for independent parameter values using knowledge of values of dependent variables.

Leaky aquifer: An aquifer whose upper and lower boundaries are aquitards, or one boundary is an aquitard and the other is an aquiclude.

Mathematical model: (a) Mathematical equations expressing the physical system and including simplifying assumptions; (b) the representation of a physical system by mathematical expressions from which the behavior of the system can be deduced with known accuracy.

Numerical model: In groundwater modeling, a model that uses numerical methods to solve the governing equations of the applicable problem. State-of-the-art numerical models have input and output capabilities supported by a graphical user interface.

Observation well: A well open to all or part of an aquifer.

Phreatic surface: The upper surface of the zone of saturation on which the water pressure in the porous medium equals atmospheric pressure.