ASCE STANDARD

ASCE/EWRI 54–10

Standard Guideline for the Geostatistical Estimation and Block-Averaging of Homogeneous and Isotropic Saturated Hydraulic Conductivity

This document uses both the International System of Units (SI) and customary units

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ENVIRONMENTAL & WATER RESOURCES INSTITUTE

American Society of Civil Engineers

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The following standards have been issued:

ANSI/ASCE 1-82 N-725 Guideline for Design and Analysis of Nuclear Safety Related Earth Structures
ASCE/EWRI 2-06 Measurement of Oxygen Transfer in Clean Water
ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs
ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) and Specifications for Masonry Structures (ACI 530.1-02/ASCE 6-02/TMS 602-02)
ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures
SEI/ASCE 8-02 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
ANSI/ASCE 9-91 listed with ASCE 3-91
ASCE 10-97 Design of Latticed Steel Transmission Structures
SEI/ASCE 11-99 Guideline for Structural Condition Assessment of Existing Buildings
ASCE/EWRI 12-05 Guideline for the Design of Urban Subsurface Drainage
ASCE/EWRI 13-05 Standard Guidelines for Installation of Urban Subsurface Drainage
ASCE/EWRI 14-05 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
ASCE 16-95 Standard for Load Resistance Factor Design (LRFD) of Engineered Wood Construction
ASCE 17-96 Air-Supported Structures
ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
ASCE 19-96 Structural Applications of Steel Cables for Buildings
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations
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ANSI/ASCE/T&DI 21.4-08 Automated People Mover Standards—Part 4
SEI/ASCE 23-97 Specification for Structural Steel Beams with Web Openings
ASCE/SEI 24-05 Flood Resistant Design and Construction
ASCE/SEI 25-06 Earthquake-Actuated Automatic Gas Shutoff Devices
ASCE 26-97 Standard Practice for Design of Buried Precast Concrete Box Sections
ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction
ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction
ASCE/SEI/SFPE 29-05 Standard Calculation Methods for Structural Fire Protection
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CI/ASCE 38-02 Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data
EWRI/ASCE 39-03 Standard Practice for the Design and Operation of Hail Suppression Projects

ASCE/EWRI 40-03 Regulated Riparian Model Water Code

ASCE/SEI 41-06 Seismic Rehabilitation of Existing Buildings

ASCE/EWRI 42-04 Standard Practice for the Design and Operation of Precipitation Enhancement Projects

ASCE/SEI 43-05 Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

ASCE/EWRI 44-05 Standard Practice for the Design and Operation of Supercooled Fog Dispersal Projects

ASCE/EWRI 45-05 Standard Guidelines for the Design of Urban Stormwater Systems

ASCE/EWRI 46-05 Standard Guidelines for the Installation of Urban Stormwater Systems

ASCE/EWRI 47-05 Standard Guidelines for the Operation and Maintenance of Urban Stormwater Systems

ASCE/SEI 48-05 Design of Steel Transmission Pole Structures

ASCE/EWRI 50-08 Standard Guideline for Fitting Saturated Hydraulic Conductivity Using Probability Density Functions

ASCE/EWRI 51-08 Standard Guideline for Calculating the Effective Saturated Hydraulic Conductivity

ASCE/SEI 52-10 Design of Fiberglass-Reinforced Plastic (FRP) Stacks

ASCE/G-I 53-10 Compaction Grouting Consensus Guide

ASCE/EWRI 54-10 Standard Guideline for the Geostatistical Estimation and Block Averaging of Homogeneous and Isotropic Saturated Hydraulic Conductivity

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FOREWORD

The Board of Direction approved revisions to the American Society of Civil Engineers' (ASCE's) Rules for Standards Committees to govern the writing and maintenance of standards developed by ASCE. All such standards are developed by a consensus standards process managed by the ASCE Codes and Standards Committee (CSC). The consensus process includes balloting by a balanced standards committee and reviewing during a public comment period. All standards are updated or reaffirmed by the same process at intervals of five to ten years.

This is a standard guideline for the geostatistical interpolation and block-averaging of saturated hydraulic conductivity in statistically homogeneous and isotropic aquifers. It 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 the American Society of Civil Engineers. This standard guideline is the third in an expected series of standards that seeks to enhance the probabilistic characterization and understanding of the behavior of a key groundwater parameter, the saturated hydraulic conductivity. The KSTAT Standards Committee published two companion standard guidelines, ASCE/EWRI Standard 50-08 (ASCE 2008a) and ASCE/EWRI Standard 51-08 (ASCE 2008b). The former addressed the optimal fitting of saturated hydraulic conductivity (K) with skewed probability density functions. The latter dealt with the estimation of the effective saturated hydraulic conductivity, a parameter that relates the average specific discharge to the average hydraulic gradient. The first two standard guidelines contain foundational material relevant to this third standard guideline that the reader might find helpful to consult.

The geostatistical estimation and block-averaging of the saturated hydraulic conductivity find numerous applications in applied groundwater hydrology. Noteworthy are the characterization of the spatial distribution of saturated hydraulic conductivity and the specification of averaged values of saturated hydraulic conductivity over volumes of aquifer, or "blocks," for the purpose of groundwater flow model calibration. The geostatistical approach used in this standard guideline takes into account the spatial statistical variability and correlation inherent to the saturated hydraulic conductivity. In this respect, this approach is advantageous relative to deterministic methods that circumvent the spatial structure of the saturated hydraulic conductivity in the search for its interpolated or block-averaged values. The geostatistical approach takes advantage of this spatial statistical structure leading to relatively simple results with promise for practical use with ease of implementation when required conditions are met in the field.

The formulas in this standard guideline involving the saturated hydraulic conductivity require that all values be expressed in the same system of units, be it the International System of Units (SI) (for example, m/day) or the common system of units in the United States (for example, ft/day).

The provisions of this document are written in permissive language and, as such, offer the user a series of options or instructions but do not prescribe a specific course of action. Significant judgment is left to the user of this document.

ASCE does not endorse commercial spreadsheets or numerical software cited in this standard guideline. Any such registered products are cited in this standard guideline to illustrate one possible way of calculating statistical parameters and special numerical functions that appear as part of this standard guideline's methodology. It is left to the users' discretion to choose and verify the accuracy of whichever computational techniques they apply in the calculations needed to implement this standard guideline's methodology.

This standard guideline has been prepared in accordance with recognized engineering principles and should not be used without the user's competent knowledge for a given application. The publication of this standard by ASCE is not intended to warrant that the information contained herein is suitable for any general or specific use, and ASCE takes no position respecting the validity of patent rights. The users are advised that the determination of patent rights or risk of infringement is entirely their own responsibility.

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STANDARD GUIDELINE FOR THE GEOSTATISTICAL ESTIMATION AND BLOCK-AVERAGING OF HOMOGENEOUS AND ISOTROPIC SATURATED HYDRAULIC CONDUCTIVITY

1.0 SCOPE

This standard guideline outlines procedures for the geostatistical estimation and block-averaging of homogeneous and isotropic saturated hydraulic conductivity. The procedures are described in the following sections, and are applicable to 1-, 2-, and 3-dimensional data sets of saturated hydraulic conductivity.

1.1 GEOSTATISTICAL ESTIMATION OF THE SATURATED HYDRAULIC CONDUCTIVITY

One purpose of this guideline is to describe a procedure for interpolating (or estimating) the (unknown) value of saturated hydraulic conductivity (K^*) at an arbitrary location in an aquifer given a sample of saturated hydraulic conductivity measurements K_1, K_2, K_3, . . . , K_n made at n locations in the same aquifer. The saturated hydraulic conductivity is treated as a spatially correlated random field (denoted by K^*). Figure 1-1 depicts the pertinent situation in this instance. The saturated hydraulic conductivity is estimated at a location 0 (which, in the 3-dimensional case, would be referenced by Cartesian coordinates x_0, y_0, z_0) using measurements K_1, K_2, K_3, . . . , K_n at various locations in an aquifer as illustrated in Fig. 1-1 (where $n = 15$ for the sake of argument). $\tilde{K}_0$ and K_0^* denote the estimated (or interpolated) value and the unknown actual value of the saturated hydraulic conductivity at location 0, respectively. The measurements of saturated hydraulic conductivity are assumed to be made with the same instrument or method that yields estimates of K^* that are representative over the domain of influence of the measuring device or methodology. In the case of pumping tests, the domain of influence may extend hundreds of meters or farther from the pumping well. The area of influence of slug tests, on the other hand, extends only a few meters (say, fewer than 10 m) from the test well. The measurements could be made on sediment or rock samples using permeameters deployed in a laboratory. One key application of $\tilde{K}_0$ is the estimation of the specific discharge at location 0 in the coordinal direction w, q_{0w}, via Darcy's law for a given value of the hydraulic gradient at 0 in the direction w, J_{0w} (ASCE 2008b).

$$q_{0w} = -\tilde{K}_0 J_{0w} \tag{1-1}$$

where the negative sign indicates that the specific discharge is in the direction of decreasing hydraulic head. Another possible application of the calculated $\tilde{K}_0$ is the estimation of the magnitude of the (advective) flux of mass m_{0w} in the direction w (a positive quantity in Eq. 1-2) of a dissolved chemical with concentration C_0 at location 0, which equals the product of q_{0w} and the concentration C_0:

$$m_{0w} = \tilde{K}_0 |J_{0w}| C_0 \tag{1-2}$$

1.2 BLOCK-AVERAGING OF THE SATURATED HYDRAULIC CONDUCTIVITY

A second purpose of this guideline is to describe a procedure for estimating the block-averaged saturated hydraulic conductivity given measurements of hydraulic conductivity at n locations in the same aquifer (that is, given K_1, K_2, K_3, . . . , K_n). The block-averaged saturated hydraulic conductivity is determined within a volume of aquifer, according to Eq. 3-1 in Section 3.2. The (unknown) block-averaged hydraulic conductivity and its estimate are denoted by K_V and $\bar{K}_V$, respectively. Figure 1-1 shows a rectangular block or volume of aquifer with vertices A, B, C, and D, over which an estimate of the block-averaged hydraulic conductivity is desired. Applications of block-averaged hydraulic conductivity are frequent in the numerical simulation of groundwater flow and solute transport. In the former case, consider two adjacent cells in a finite-difference grid used in a numerical simulation of groundwater flow, as shown in Fig. 1-2. Cells 1 and 2 feature block-averaged saturated hydraulic conductivities K_{V1} and K_{V2}, respectively.

It is known from groundwater theory (Fetter 2001, p. 106) that the groundwater discharge (q_{12}) between the two cells shown in Fig. 1-2 is given by Eq. 1-1 written in finite-difference form:

$$q_{12} = K_H b \frac{h_1 - h_2}{d_{12}} \tag{1-3}$$

in which b is the width of the cells perpendicular to the direction of flow on the plane of Fig. 1-2; h_1 and