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# Standard Guide for Selection of Methods for Assessing Groundwater or Aquifer Sensitivity and Vulnerability[1]

This standard is issued under the fixed designation D6030; 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 information needed to select one or more methods for assessing the sensitivity of groundwater or aquifers and the vulnerability of groundwater or aquifers to water-quality degradation by specific contaminants.

1.2 This guide may not be all-inclusive; it offers a series of options and does not specify a course of action. It should not be used as the sole criterion or basis of comparison, and does not replace professional judgment.

1.3 This guide is to be used for evaluating sensitivity and vulnerability methods for purposes of land-use management, water-use management, groundwater protection, government regulation, and education. This guide incorporates descriptions of general classes of methods and selected examples within these classes but does not advocate a particular method.

1.4 *Limitations*—The utility and reliability of the methods described in this guide depend on the availability, nature, and quality of the data used for the assessment; the skill, knowledge, and judgment of the individuals selecting the method; the size of the site or region under investigation; and the intended scale of resulting map products. Because these methods are being continually developed and modified, the results should be used with caution. These techniques, whether or not they provide a specific numeric value, provide a relative ranking and assessment of sensitivity or vulnerability. However, a relatively low sensitivity or vulnerability for an area does not preclude the possibility of contamination, nor does a high sensitivity or vulnerability necessarily mean that groundwater or an aquifer is contaminated.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.6.1 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analytical methods for engineering design.

1.7 *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.*

1.8 *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 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

[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.

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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**

D5880 Guide for Subsurface Flow and Transport Modeling (Withdrawn 2015)[3]

D6026 Practice for Using Significant Digits in Geotechnical Data

## 3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *groundwater region, n*—an extensive area where relatively uniform geology and hydrology controls groundwater movement.

3.2.2 *hydrogeologic setting, n*—a composite description of all the major geologic and hydrologic features which affect and control groundwater movement into, through, and out of an area (**1**).[4]

3.2.3 *sensitivity, n—in groundwater*, the potential for groundwater or an aquifer to become contaminated based on intrinsic hydrogeologic characteristics. Sensitivity is not dependent on land-use practices or contaminant characteristics. Sensitivity is equivalent to the term "*intrinsic groundwater vulnerability*" (**2**).

3.2.3.1 *Discussion*—Hydrogeologic characteristics include the natural properties of the soil zone, unsaturated zone, and saturated zone.

3.2.4 *vulnerability, n—in groundwater*, the relative ease with which a contaminant can migrate to groundwater or an aquifer of interest under a given set of land-use practices, contaminant characteristics, and sensitivity conditions. Vulnerability is equivalent to "specific groundwater vulnerability."

## 4. Significance and Use

4.1 Sensitivity and vulnerability methods can be applied to a variety of hydrogeologic settings, whether or not they contain specifically identified aquifers. However, some methods are best suited to assess groundwater within aquifers, while others assess groundwater above aquifers or groundwater in areas where aquifers have not been identified.

4.1.1 Intergranular media systems, including alluvium and terrace deposits, valley fill aquifers, glacial outwash, sandstones, and unconsolidated coastal plain sediments are characterized by intergranular flow, and thus generally exhibit slower and more predictable groundwater velocities and directions than in fractured media. Such settings are amenable to assessment by the methods described in this guide. Hydrologic settings dominated by fracture flow or flow in solution openings are generally not amenable to such assessments, and application of these techniques to such settings may provide misleading or totally erroneous results.

4.2 The methods discussed in this guide provide users with information for making land- and water-use management decisions based on the relative sensitivity or vulnerability of underlying groundwater or aquifers to contamination. Most sensitivity and vulnerability assessment methods are designed to evaluate broad regional areas for purposes of assisting federal, state, and local officials to identify and prioritize areas where more detailed assessments are warranted, to design and locate monitoring systems, and to help develop optimum groundwater management, use and protection policies. However, some of these methods are independent of the size of the area evaluated and, therefore, can be used to evaluate the aquifer sensitivity and vulnerability of a specific area.

4.3 Many methods for assessing groundwater sensitivity and vulnerability require information on soils, and for some types of potential groundwater contaminants, soil is the most important factor affecting contaminant movement and attenuation from the land surface to groundwater. The relatively large surface area of the clay-size particles in most soils and the soils' content of organic matter provide sites for the retardation and degradation of contaminants. Unfortunately, there are significant differences in the definition of soil between the sciences of hydrogeology, engineering, and agronomy. For the purposes of this guide, soils are considered to be those unconsolidated organic materials and solid mineral particles that have been derived from weathering and are characterized by significant biological activity. These typically include unconsolidated materials that occur to a depth of 2 to 3 m or more.

4.3.1 In many areas, significant thicknesses of unconsolidated materials may occur below the soil. Retardation, degradation, and other chemical attenuation processes are typically less than in the upper soil horizons. These underlying materials may be the result of depositional processes or may have formed in place by long-term weathering processes with only limited biological activity. Therefore, when compiling the data required for assessing groundwater sensitivity and vulnerability, it is important to distinguish between the soil zone and the underlying sediments and to recognize that the two zones have significantly different hydraulic and attenuation properties.

## 5. Description of Methods

5.1 *Hydrogeologic Settings and Scoring Methods*—This group of methods includes those that involve geologic mapping, evaluation, and scoring of hydrogeologic characteristics to produce a composite sensitivity map or composite vulnerability map, or both. The methods range from purely descriptive of hydrogeologic settings to methods incorporating numerical scoring. They can include descriptive information or quantitative information, or both, and the maps can be applied as a "filter" to exclude specific hydrogeologic units from further consideration or select sensitive areas for further study.

5.1.1 The concept of assessing groundwater sensitivity and vulnerability is relatively recent and still developing. Thus, the methods presented differ because they have been developed for different purposes by different researchers using various types of data bases in several hydrogeologic settings. These methods have been divided into three groups: assessments using hydrogeologic settings without scoring or rankings, assessments in which hydrogeologic setting information is combined with

[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.

ranking or scoring of hydrologic factors, and assessments using scoring methods applied without reference to the hydrogeologic setting. The groups are not exclusive but overlap. Each of these methods produces relative, not absolute, results whether or not it produces a numerical score. Sensitivity analyses can be used as the basis for a vulnerability assessment by adding the information on potential point and non-point contaminant sources.

5.1.2 *Hydrogeologic Settings, No Scoring or Ranking*—Hydrogeologic mapping has been widely used to provide aquifer sensitivity information. This subgroup of methods includes those that generally present information as composite hydrogeologic maps that can be used for multiple purposes. The maps can be used individually to make a variety of land-use decisions or used as a basis for groundwater and aquifer sensitivity evaluations. Although derivative groundwater and aquifer sensitivity maps can be prepared, a geologic or hydrogeologic map could potentially be used to assess sensitivity. In settings where quantitative data are lacking, hydrogeologic maps can allow the same conclusions, with the same level of confidence, as scoring methods. Hydrogeologic settings were mapped in detail without scoring or ranking by Hearne and others (**3**).

5.1.2.1 Sensitivity assessments based on hydrogeologic settings with no scoring or ranking can be used to assess groundwater or aquifer vulnerability by overlaying information on potential point or non-point contamination sources. For example, the sensitivity map included in Ref (**3**) has been used in combination with a series of maps entitled "Land Uses Which Affect Ground-Water Management" (**4**) to conduct vulnerability assessments at specific sites.

5.1.3 *Hydrogeologic Settings with Ranking or Scoring, or Both*—This group of methods includes those which assess groundwater or aquifer sensitivity within or among various hydrogeologic settings using specific criteria to rank or score areas beneath which the groundwater or aquifers have different potentials for becoming contaminated. The assessment is usually based on two or more hydrogeologic criteria. For example, material texture and depth to aquifer are parameters that are commonly used to establish criteria (**5-10**). Criteria, once defined, can then be ranked or scored, or both.

5.1.3.1 Assessing vulnerability from point and non-point sources of potential contamination (for example, leaking tanks, waste generators, landfills, and abandoned hazardous waste sites) is accomplished by mapping their location on a sensitivity map (for example, numerous waste-generation sites in an area of low sensitivity would result in a relatively low vulnerability rank, all other factors being equal). This mapping method is particularly useful for evaluating the vulnerability of a large region. However, it can also be used to target smaller areas of particular concern where more detailed investigations may be needed. For example, Shafer (**11**) mapped regional aquifer vulnerability based on sensitivity analysis. Bhagwat and Berg (**12**) defined aquifer sensitivity according to depth to aquifers and the characteristics of the geologic materials. The sensitivity map was combined with information showing the distribution of waste-source sites per defined area per square-kilometre. Highly vulnerable areas have aquifers at or near the surface and contain numerous point sources of potential contamination with mobile contaminants. Areas of low vulnerability have deep groundwater or no aquifers and contain few potential contaminant sources or relatively immobile contaminants. This vulnerability information was then used to establish groundwater protection planning regions.

5.1.4 *Scoring, Without Hydrogeologic Settings*—This category includes those methods that use qualitative ranking or quantitative scoring with hydrogeologic information, but without subdividing the area on the basis of hydrogeologic settings. Methods were developed to have universal application and were intended to be used consistently to provide uniform results regardless of location. The methods are useful for applications that require a consistent approach over large areas, however, these methods can be complex and may require much unnecessary data preparation. Furthermore, because criteria selection and ranking are subjective, the final scores may be misleading.

5.1.4.1 These methods classify a site or region based on a ranking or a numerical score derived from hydrogeological information irrespective of the different hydrogeologic settings that may be present within the mapped area. Scores are calculated from equations based on criteria assumed to apply to different geographic areas and different hydrogeologic conditions (**1,13–14**). For example, in one area (**15**), drilling logs and soil survey maps were used to prepare maps based on hydraulic conductivity which was inferred from the percent and thickness of surface organic matter. Attenuation potentials of soil selected in another area (**16**) were mapped based on soil depth, permeability, drainage class, organic matter content, pH, and texture.

5.2 *Process-Based Simulation Models*—These methods for assessment of groundwater sensitivity and vulnerability use a variety of models, each of which simulates some combination of the physical, chemical, and biological processes that control the movement of water and chemicals from land surface through the unsaturated zone to and through the saturated zone. These processes are formulated in terms of equations that are derived theoretically or empirically. Analytical or numerical techniques are used, usually within a computer program, to solve the equations. The solutions take the form of predicted rates of water and chemical movement as a function of location and time. Models differ greatly in the degree of complexity used to incorporate actual processes, the amount of data required, the intended scale of the application, and the domain simulated. The latter criterion is arbitrarily selected here to categorize different simulation models. The three categories are: Root Zone Models, which simulate water and chemical movement through the portion of the unsaturated zone that is affected by vegetation; Unsaturated Zone Models, which simulate transport through the entire thickness of the unsaturated zone; and Saturated Zone Models which deal with processes occurring beneath the water table. Within each category there can be a wide range of model complexity with some models overlapping between different categories. Unsaturated-zone and root-zone models have been cataloged by van der Heijde (**17,18**) and van der Heijde and Elnawawy (**19**).