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Standard Guide for Conceptualization and Characterization of Ground-Water Systems[1]

This standard is issued under the fixed designation D 5979; 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 an integrated, stepwise method for the qualitative conceptualization and quantitative characterization of ground-water flow systems, including the unsaturated zone, for natural or human-induced behavior or changes.

1.2 This guide may be used at any scale of investigation, including site-specific, subregional, and regional applications.

1.3 This guide describes an iterative process for developing multiple working hypotheses for characterizing ground-water flow systems. This process aims at reducing uncertainty with respect to conceptual models, observation, interpretation, and analysis in terms of hypothesis and refinement of the most likely conceptual model of the ground-water flow system. The process is also aimed at reducing the range of realistic values for parameters identified during the characterization process. This guide does not address the quantitative uncertainty associated with specific methods of hydrogeologic and ground-water system characterization and quantification, for example, the effects of well construction on water-level measurement.

1.4 This guide addresses the general procedure, types of data needed, and references that enable the investigator to complete the process of analysis and interpretation of each data type with respect to geohydrologic processes and hydrogeologic framework. This guide recommends the groups of data and analysis to be used during each step of the conceptualization process.

1.5 This guide does not address the specific methods for characterizing hydrogeologic and ground-water system properties.

1.6 This guide does not address model selection, design, or attribution for use in the process of ground-water flow system characterization and quantification. This guide does not address the process of model schematization, including the simplification of hydrologic systems and the representation of hydrogeologic parameters in models.

1.7 This guide does not address special considerations required for characterization of karst and fractured rock terrain. In such hydrogeologic settings, refer to Quinlan **(1)**[2] and Guide D 5717 for additional guidance.

1.8 This guide does not address special considerations regarding the source, fate, and movement of chemicals in the subsurface.

1.9 *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.*

1.10 *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:*

2.1.1 This procedure is used in conjunction with the following ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 5254 Practice for the Minimum Set of Data Elements to Identify a Ground Water Site[3]

D 5408 Guide for the Set of Data Elements to Describe a Ground Water Site; Part 1—Additional Identification Descriptors[3]

D 5409 Guide for the Set of Data Elements to Describe a Ground Water Site; Part 2—Physical Descriptors[3]

D 5410 Guide for the Set of Data Elements to Describe a Ground Water Site; Part 3—Usage Descriptors[3]

D 5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem[3]

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[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 Ground Water and Vadose Zone Investigations.

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[2] The boldface numbers given in parentheses refer to a list of references at the end of the text.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

D 5474 Guide for Selection of Data Elements for Ground-Water Investigations[3]
D 5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling[3]
D 5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling[3]
D 5717 Guide to Design of Ground-Water Monitoring Systems in Karst and Fractured-Rock Aquifers[3]
D 5730 Guide to Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone, and Ground Water[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *conceptual model*—an interpretation or working description of the characteristics and dynamics of the physical system.

3.1.2 *ground-water flow model*—application of a mathematical model to represent a regional or site-specific ground-water flow system.

3.1.3 *hydrologic system*—the general concepts of the hydrologic elements, active hydrologic processes, and the interlinkages and hierarchy of elements and processes.

3.1.4 For definitions of other terms used in this guide, see Terminology D 653 and Guide D 5447.

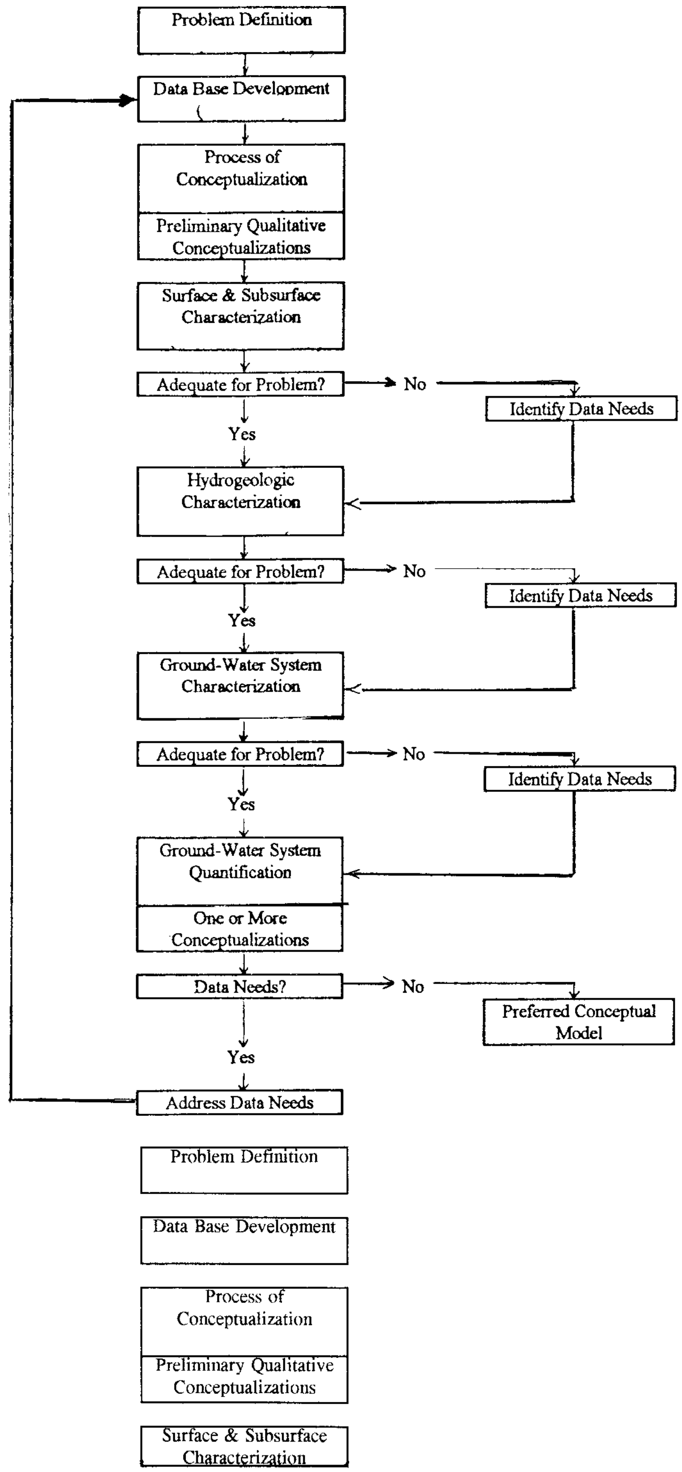
4. Summary of Guide

4.1 This guide presents an integrated approach for conceptualizing and characterizing ground-water systems. The conceptualization and characterization process includes: Problem Definition and Data Base Development (Section 6); Preliminary Conceptualization (Section 7); Surface Characterization (Section 8); Subsurface Characterization (Section 9); Hydrogeologic Characterization (Section 10); Ground-Water System Characterization (Section 11); and Ground-Water System Quantification (Section 12) (see Fig. 1). Conceptualization and characterization is an iterative process beginning with a theoretical understanding of the ground-water system followed by data collection and refinement of the understanding. Additional data collection and analysis, and the refinement of the ground-water system conceptual model occurs during the entire process of conceptualization and characterization, and during ground-water model development and use (see Fig. 1).

4.2 This guide presents an approach that can be used at any scale. The nature of the problem to be solved will determine the type and scale of data collected.

5. Significance and Use

5.1 Conceptualization and characterization of a ground-water system is fundamental to any qualitative or quantitative analysis. This conceptualization begins with simple abstractions in the investigator's mind, emphasizing the major components of the studied system, that can be rendered in qualitative terms or simple illustrations. The extent of further development of the representation of the system depends on the character of the ground-water problem and the project objective. The abstract concept may suffice, or it may be further defined and quantified through use of analytical models of increasing complexity, and, in some cases, numerical models may be employed. If numerical models are used, the level of



NOTE 1—Conceptualization and characterization is an iterative process beginning with a theoretical understanding of the ground-water system followed by data collection and refinement of the understanding. Additional data collection and analysis, and the refinement of the ground-water system conceptual model occurs during the process of conceptualization and characterization, and during ground-water model development and use.

FIG. 1 Procedure for Conceptualization and Characterization of Ground-Water Flow Systems (32)

detail and sophistication of features represented in the model is likely to increase as the project develops. Evolution of conceptualization of a ground-water flow system should be terminated when the results of the related analyses are sufficient for the problem being addressed.

5.2 This guide may be used in the following:

5.2.1 Evaluating natural variations in ground-water flow systems.

5.2.2 Evaluating anthropogenic stresses on ground-water flow systems, such as pumping for water supply, irrigation, induced infiltration, or well injection.

5.2.3 Evaluating presence and velocity of ground-water contaminants.

5.2.4 Designing and selecting mathematical models to simulate ground-water systems; and completing model schematization and attribution based on the problem defined, characterized ground-water flow system, and model(s) selected.

5.2.5 Designing ground-water remediation systems.

5.3 This guide is a flexible description of specific techniques and investigation requirements; methods defined by other ASTM Standards or non-ASTM techniques may be appropriate in some circumstances and, after due consideration, some of the techniques herein may be omitted, altered, or enhanced.

5.3.1 A comprehensive list of items to be considered conceptualization and characterization are included in the main headings (Sections 6 through 13) and first subheadings (for example, 7.1 and 8.1).

5.3.2 In karst and fractured rock hydrogeologic settings, this guide should be used in conjunction with Guide D 5717.

5.4 The methods and amount of effort required for conceptualization, characterization, and quantification of ground-water systems for modeling or other applications will vary with site conditions, objectives of investigation, and investigator experience. This guide does not replace proper academic training and experience in hydrogeologic principles, or in ground-water system analysis and quantification. This guide does not set mandatory guidelines and does not constitute a list of necessary steps or procedures for all investigations.

5.5 This guide may be used for project planning and data collection, but does not provide specific aspects for field characterization techniques. Refer to Table X1.1 in Guide D 5730, Practice D 5254, and Refs **(2, 3, 4,** and **5)** for further guidance regarding field characterization techniques.

5.6 This guide may be used to generate the necessary information as part of the process for model selection, design, and as input to model schematization, including the simplification of hydrologic systems and the representation of hydrogeologic parameters in models. Refer to Ref **(6)** for further guidance.

6. Problem Definition and Data Base Development

6.1 *Define the Objectives of the Project*—Once the objectives are defined, identify the appropriate facets and scale of the ground-water system for characterization.

6.2 *Define the Site*—The boundaries of a site are defined using one or more of the following considerations: natural site characteristics (topography, soils, geology, hydrology, biota), current and past land use and ownership, or known or suspected extent of current or anticipated project-related stresses, which may include cones of depression or contaminant migration. If site boundaries are initially defined by ownership, natural site characteristics of a broader scale should be evaluated to determine whether the scope of at least parts of the investigation should include areas that are off-site. For example, investigations of ground-water contamination should include areas of potential sources upgradient and potential migration paths down-gradient from a site.

6.3 *Gather Data from Existing Sources*—This step involves locating, collecting, and organizing the data needed (see Table 1) to solve the problem into a manageable data base. See Practice D 5254 and Guides D 5408, D 5409, D 5410, D 5474, and D 5730 for data elements to identify a ground-water site.

6.3.1 Collect data, such as maps, tables, and reports, from available published and unpublished sources, and field and

TABLE 1 Data Topics and Types

Topography and Remote Sensing:	
(a)	Topography
(b)	Aerial photography
(c)	Satellite imagery
(d)	Multispectral data
(e)	Thermal imagery
(f)	Radar, side-looking airborne radar, microwave imagery
Geomorphology:	
(a)	Surficial geology or geomorphology maps
(b)	Engineering geology maps
(c)	Surface water inventory maps
(d)	Hydrography digital line graphs
Geology:	
(a)	Geologic maps and cross sections
(b)	Lithologic or drillers logs, or both
Geophysics:	
(a)	Gravity, electromagnetic magnetics, resistivity, and seismic survey data or interpretations, or both
(b)	Natural seismic activity data
(c)	Borehole geophysical data
Climate:	
(a)	Precipitation data
(b)	Temperature, humidity, and wind data
(c)	Evaporation data
(d)	Effects of climate change on hydrologic system information
Vegetation:	
(a)	Communities or species maps, or both
(b)	Density map
(c)	Agricultural species, crop calendars, consumptive use data
(d)	Land use—Land cover maps
Soils:	
(a)	Soil surveys
(b)	Soil properties determined from laboratory analysis
Hydrology:	
(a)	Potentiometric head data
(b)	Subsurface test information
(c)	Subsurface properties determined from laboratory analyses
(d)	Previous work regarding modeling studies, hydrogeologic and ground-water system maps
(e)	Spring and seep data
(f)	Surface water data
(g)	Well design, construction, and development information
Hydrochemistry/Geochemistry (Related to Ground-Water Flow System):	
(a)	Subsurface chemistry derived from well samples
(b)	Surface water chemistry
(c)	Rock and soil chemistry
(d)	Water quality surveys
Anthropogenic Aspects:	
(a)	Planimetric maps
(b)	Land use—Land cover maps
(c)	Roads, transportation, political boundary DLGs
(d)	Land ownership maps include historical information, if available
(e)	Resource management maps

laboratory studies. Note the methods used to collect and analyze the data. Note levels of quality assurance and quality control as required by the project.

6.3.2 Collect data from interviews of local and regionally knowledgeable people. This may include, but is not limited to, worker histories, former practices, and engineering activities that either changed the site or provide historical data (location of old wells, contaminant history, and so forth).

6.4 *Organize and Prepare Data Bases Based on Project Objectives*—This step involves organizing the data into appropriate data bases that could include, but are not limited to: geomorphology, geology, geophysics, climate, vegetation, soils, hydrology, hydrochemistry/geochemistry, and anthropogenic aspects (see Table 2).[4]

7. Preliminary Conceptualization

7.1 Conduct field conceptualization using data bases developed under Section 6. In areas where field data are sparse, basic photointerpretation and terrain analysis techniques may be applied to remote sensing data, aerial photography, and topographic maps to acquire information, and may be used to quantify and distribute hydrogeologic and ground-water system parameters.

7.1.1 Analyze existing data. This includes both the natural and anthropogenic features of the site. This preliminary analysis may include land cover patterns (vegetation, soils, surface water type and distribution, topography, geology), landforms (surficial geology and geography), and drainage analysis.[5]

7.1.2 Conduct field reconnaissance to relate the preliminary analysis of the information collected to study site conditions.[6]

7.2 Conduct qualitative ground-water system conceptualization. This results in the development of one or more initial conceptual models that will be used for characterization and quantification. This qualitative analysis uses the same logic presented in Sections 8 through 12 for quantitative analysis.

7.2.1 Qualitatively characterize the study area surface using procedures stated in Section 8.

7.2.2 Qualitatively characterize the study area subsurface geologic framework using procedures stated in Section 9.

7.2.3 Qualitatively characterize the study area hydrogeologic framework using procedures stated in Section 10.

7.2.4 Qualitatively characterize the study area ground-water system using procedures stated in Section 11. The resulting ground-water system conceptual model, to be used for quantitative characterization, includes a qualitative assessment of how water enters, moves through or is stored in, and leaves the ground-water system. The potentiometric surfaces and boundary conditions of each aquifer in the ground-water system are conceptualized at this time.

TABLE 2 Data Bases

Geomorphology:	
(a)	Topographic map or digital elevation model, or both
(b)	Drainage trace map
Geology:	
(a)	Geologic map and stratigraphic column
(b)	Surficial geology map and stratigraphic column
(c)	Geologic cross sections
(d)	Lithologic or driller's logs, or both
Geophysics:	
(a)	Gravity maps and data
(b)	Magnetic maps and data
(c)	Resistivity maps and data
(d)	Seismic and earthquake activity maps and data
(e)	electromagnetic induction data
Meteorology and Climate:	
(a)	Precipitation data
(b)	Temperature data
(c)	Evaporation data
(d)	Solar radiation data
Vegetation:	
(a)	Vegetation type and distribution maps
(b)	Consumptive water use data
Soils:	
(a)	Soil type and characteristics maps
(b)	Soil properties data
Hydrology:	
(a)	Water well data
(b)	Potentiometric surface maps
(c)	Springs and seeps data
(d)	Surface water data
(e)	Aquifer properties data
Hydrochemistry/Geochemistry (as Related to Ground-Water Flow Systems):	
(a)	Isotope hydrochemistry
(b)	Organic hydrochemistry
(c)	Inorganic hydrochemistry
(d)	Soil, chemical precipitates, and rock geochemistry
Anthropogenic Aspects:	
(a)	Political boundaries maps
(b)	Land ownership maps
(c)	Land use—Land cover maps including historical information, if available
Hydrogeologic Characterization:	
(a)	Hydrogeologic table of attributes
(b)	Hydrogeologic map
(c)	Hydrogeologic cross-sections and stratigraphic columns
Ground-Water System Characterization:	
(a)	Ground-water system tables for recharge and discharge types and amounts
(b)	Ground-water system maps showing recharge, discharge, and flow system
(c)	Ground-water system cross sections showing recharge, discharge, and flow system
(d)	Potentiometric surface maps for each hydrologic layer

7.2.5 Describe and visualize the ground-water system conceptual model using cross sections and plan view illustrations. This ground-water system conceptual model may be modified at any stage of quantitative characterization (see Sections 8 through 12).

8. Surface Characterization

8.1 Conduct surface characterization of anthropogenic and natural features and processes at or near ground surface.

8.1.1 Conduct anthropogenic effects analysis to show hydrologic land use. Anthropogenic effects analysis includes, but is not limited to, irrigation or agricultural consumptive use of water; and industrial, municipal, and domestic water use.

8.1.2 Conduct vegetation analysis including vegetation type and distribution, consumptive water use data, and the hydrologic land use. See Ref **(9)** for guidance and references.

[4] Quality assurance/quality control should be maintained throughout the project. Data may be organized into three types: 1) raw, original data collected in the field or laboratory, or both; 2) extracted data produced from the original, raw data base to solve the study purposes, goals, and objectives; and 3) interpretations and analyses of both raw or extracted data as applied to solving the problem.

[5] See Ref **(7)** and Ref **(8)** for interpretations related to drainage density, drainage network patterns, valley morphological patterns, and channel patterns and longitudinal profiles.

[6] The importance of this step will vary depending on site conditions and investigator experience. This step is especially important when site conditions are complex or the investigator's experience is limited regarding site conditions.

8.1.3 Conduct topography analysis including terrain, slope characteristics, hydrologic system continuity, and boundary locations. See Ref **(10)** for guidance and references.

8.1.4 Conduct surface water classification and distribution analysis, including classification and distribution of surface water flow (gaining and losing streams, constant or ephemeral stream flow; baseflow analysis), springs, lakes, and oceans. See Ref **(11)** for guidance and references.

8.1.5 Conduct climate analysis, including types and distribution of precipitation and temperatures, wind effects, and evapotranspiration potential. See Ref **(3)** for guidance and references.

8.1.6 Conduct pedogenic process and deposits analysis, including soil framework (horizons) and thickness, and soil permeability analysis, using standard pedogenic methods **(12,13,14,15,16,17)**. It may be possible to use existing soil information for this analysis.

8.1.7 Conduct a geomorphologic process and deposits analysis, including maps depicting the type, properties, and distribution of geomorphic materials; geologic outcrops; landforms and slope; or other geomorphic characteristics needed to understand and solve the problem.[7]

9. Subsurface Characterization

9.1 Determine stratigraphic and lithologic units (soil and rock) using the soils, geology, and geophysics data bases and analysis, and surface characterization results. The stratigraphy or lithology of the subsurface framework, or both, is determined for the study area using standard geologic methods **(19,20)**, and geophysical methods **(2,3,4,5,** and **21)**.

9.1.1 Geologic maps and cross sections, subsurface investigation logs, and stratigraphic columns are used, in conjunction with surface characterization and geophysical data and analysis, to develop a part of the geologic framework that represents the distribution of lithologic units.

9.1.2 Stratigraphic continuity of the geologic units may be evaluated using cross sections derived from geologic maps, well logs, and geophysical data.

9.2 Determine structural and geomorphologic discontinuities and stress history of the framework (for example, faults, fracture zones, karst) in the study area using the geology (geologic maps and cross sections) and geophysics analysis, surface characterization, geologic stratigraphic columns, and standard geologic and hydrogeologic methods (see Refs **(2,3,5,** and **22)**).

9.3 Develop subsurface geologic framework geometries and cross sections using all of the soils, geology, geomorphology, and geophysics databases constructed during the preliminary conceptualization and surface characterization process, and the on-going subsurface characterization process. See Refs **(19)** and **(20)** for guidance.

10. Hydrogeologic Characterization

10.1 Characterize, quantify, and evaluate the uncertainty of the hydrostratigraphic units in terms of thickness, porosity, permeability, hydraulic conductivity (or soil moisture characteristic functions), transmissivity, and storativity. Primary, or matrix, porosity and permeability values, or hydraulic conductivity (or soil moisture characteristic functions), transmissivity, and storativity values may be quantified based on aquifer tests, laboratory analysis, or parameter estimation. Refer to 2.1 for ASTM Standards and the Reference Section for major non-ASTM references for information on characterization and quantification procedures. For specific vadose zone references and procedures, see Ref **(23)** and Guide D 5730.

10.1.1 Determine the continuity, geometry and spatial distribution, and thickness (total and saturated) of the hydrostratigraphic units.

10.1.2 Determine the isotropy/anisotropy of the hydrostratigraphic units.

10.1.3 Determine the homogeneity/heterogeneity of the hydrostratigraphic units.

10.1.4 Determine the hydrologic response of the hydrostratigraphic units (aquifer or confining unit). These units may be aquifers (conduits) or confining units (barriers) on the basis of hydraulic conductivity, saturated thickness, and continuity.

10.2 Characterize, quantify, and evaluate the uncertainty of the hydrostructural units, such as faults, fracture zones, fractured materials and karst conduits, in terms of thickness, porosity, permeability, hydraulic conductivity, transmissivity, and storativity. Fracture and fracture/karst porosity and permeability values, or hydraulic conductivity, transmissivity, and storativity values may be quantified based on aquifer tests, laboratory analysis, or parameter estimation.[8] Refer to 2.1 for ASTM Guides and Standards. For specific vadose zone references and procedures, see Ref (**23**) and Guide D 5730. For fractured rock characterization, see Ref (**16**) and Ref (**27**).

10.2.1 Determine the continuity, geometry and spatial distribution, and thickness (total and saturated) of the hydrostructural units.

10.2.2 Determine the isotropy/anisotropy of the hydrostructural units.

10.2.3 Determine the homogeneity/heterogeneity of the hydrostructural units.

10.2.4 Determine the hydrologic response of the hydrostructural units (aquifer or confining unit). These units may be aquifers (conduits) or confining units (barriers) on the basis of hydraulic conductivity, saturated thickness, and continuity.

10.3 Characterize and quantify the hydrogeologic framework.

10.3.1 Each hydrostratigraphic and hydrostructural unit, defined as a discrete volume element of the subsurface geologic framework, is evaluated based on the scale (site, local, or regional evaluation), temporal aspects (steady-state or transient analysis; daily, seasonal, annual analysis), and scope (saturated

[7] The geomorphologic processes, such as weathering, mass wasting, fluvial, eolian, glacial, oceanic, and ground water; and responses, such as: landforms and deposits, are interpreted using the landform, drainage, and land cover analyses derived from both on-site observations and databases created from remote sensing data, aerial photographs, and topographic maps. The general geomorphic process and response systems are described in more detail in geomorphology texts, such as Ref **(18)**.

[8] For additional information on the effects of subsurface geochemical processes on the hydrologic system, see Ref **(10)**. The methods used to evaluate these effects may include fault and fracture zone analysis **(24)**, the hydrochemistry and geochemistry of the aquifer material and related flow system **(25)**, and the general surface and subsurface evaluation of karst terrains (including regolith) **(26)**.

or unsaturated zone evaluation, two-dimensional or three-dimensional analysis) of the problem.

10.3.2 The hydrostratigraphic and hydrostructural units have been assigned numerical attributes, and can now be combined as units of relatively uniform character such as aquifers (conduits) or confining layers (barriers), isotropic or anisotropic, homogeneous or heterogeneous, and confined or unconfined parts of the hydrogeologic framework. As a result, these combined hydrogeologic units may be classified in any combination of these characteristics, and may be combined together, or further differentiated, based on the constraints of the problem.

10.3.3 In karst and fractured rock hydrogeologic settings, refer to Guide D 5717 for special approaches required for characterization and quantification of hydrogeologic properties. Refer to 2.1 for ASTM Standards for information on characterization and quantification procedures.

11. Ground-Water System Characterization

11.1 Characterize and evaluate uncertainty of the recharge areas and determine the type, amount, and distribution of recharge using surface, subsurface, and hydrogeologic analysis. Recharge is evaluated based on the scale, temporal aspects, and scope of the problem. Estimate recharge derived from: infiltration of precipitation; infiltration of surface water; return-flow from irrigated lands; inter-aquifer leakage; flux through natural or study area boundaries; and anthropogenic" sources." See Refs **(28)** and **(29)** for further guidance.

11.2 Characterize and evaluate uncertainty of the discharge areas and determine the type, amount, and distribution of discharge using surface, subsurface, and hydrogeologic analysis. Discharge is evaluated based on the scale, temporal aspects, and scope of the problem. Estimate discharge derived from: springs and seeps; surface water bodies; evapotranspiration from vegetation; well discharge; inter-aquifer leakage; flux through natural and study area boundaries; and anthropogenic "sources." See Ref **(5)** for further guidance.

11.3 Characterize and quantify the chemical constituents, both natural and anthropogenic, that pertain to characterizing the ground-water flow system. Chemical constituents are evaluated based on the scale, temporal aspects, and scope of the problem. See Refs **(5)** and **(30)** for further guidance.

11.3.1 Analyze the natural and anthropogenic chemical inputs to the subsurface hydrologic system from atmospheric, vegetation, and surface water sources.

11.3.2 Analyze the natural and anthropogenic chemical inputs to the subsurface hydrologic system from soil and rock materials.

11.3.3 Use the natural and anthropogenic chemical information and knowledge of the chemical processes, including, but not limited to, the biochemical, geochemical, and hydrochemical processes, to determine subsurface flow paths and estimate flow velocities, and to aid in characterizing the ground-water flow system. Useful information may include, but is not limited to, isotopes, natural or anthropogenic tracers, and ground-water chemical species evolution. For further guidance, see Boulding **(5)**.

11.4 Characterize and quantify the ground-water system using Problem Definition and Data Base Development (see Section 6); Preliminary Conceptualization (see Section 7); Surface Characterization (see Section 8); Subsurface Characterization (see Section 9); Hydrogeologic Characterization (see Section 10); and Ground-Water System Characterization (see Section 11).[9] Ground-water system characterization and quantification is based on the scale (site, local, or regional evaluation), temporal aspects (steady-state or transient analysis; daily, seasonal, annual analysis), and scope (saturated or unsaturated zone evaluation, two-dimensional or three-dimensional analysis) of the problem. See Refs **(7)** and **(31)** for guidance.

11.4.1 Characterize and quantify the initial conditions and boundary conditions of the ground-water system. See Guide D 5609; Guide D 5610; and Ref **(6)** for guidance.

11.4.2 Characterize the flow paths and construct the potentiometric surfaces for each hydrogeologic unit or layer of the ground-water system. See Ref **(5)** for further guidance.

11.4.3 Characterize, quantify, and balance the ground-water system water budget. Steady-state water budgets may be quantified by balancing the estimates of recharge (see 11.1) with the estimates of discharge (see 11.2). See Ref **(5)** for further guidance.

12. Ground-Water System Quantification

12.1 Exploratory ground-water modeling of one or more conceptual models, particularly the matching of the results of numerical models, with observations of heads and fluxes, may be used for the quantification of the hydrodynamics of the characterized ground-water system, for checking the ground-water flow system characterization for deficiencies (conceptual model or attributes), and for determining subsequent field sampling programs.[10]

12.2 Collect additional field data as required to address the identified data gaps.

12.3 As additional hydrogeologic and ground-water system data are collected or become available, the ground-water flow system conceptualization and characterization is refined (see Fig. 1).

12.4 If appropriate, select a modeling code, construct and calibrate a model and perform sensitivity analysis (see Guide D 5447 for guidance).

13. Report

13.1 If the characterized and quantified ground-water flow system is a product unto itself, then a report summarizing the data collected and the analyses performed should be prepared. If the characterized and quantified ground-water flow system is a part of another study or site characterization report, then the report for this activity can be included as a section.

13.2 The report should include a review of the assumptions used to characterize and quantify the ground-water flow

[9] The data bases needed for this analysis include recharge maps, discharge maps, topographic maps (or DEMs), water level data (heads), and hydrogeologic characterization. Hydrochemistry data, including the distribution of isotopes and hydrochemical species, and flow path chemistry, may help to confirm flow path vector distribution.

[10] Ground-water modeling may be used for checking the hydrogeologic attributes, such as hydraulic conductivity, transmissivity, and storativity, and the ground-water system attributes, such as water budgets, potentiometric surfaces, recharge, and discharge amounts, of the characterized ground-water system.

system. Each of the sections mentioned previously that are relevant to the project should be mentioned in the report.

14. Keywords

14.1 characterization; conceptualization; ground water; ground-water modeling; ground-water systems

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