A Glossary of Hydrogeology

John M. Sharp, Jr.

THE GROUNDWATER PROJECT

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Cover Image: Balmorhea Springs of Texas. Clockwise from top: San Solomon Springs, one of the world's largest spring-fed swimming pools (Texas Parks and Wildlife, 2023); East Sandia Spring (photo courtesy of Rebecca Nunu, 2022); Giffin Spring (Sharp, personal image, 2023); Phantom Lake Spring (http://www.phantomlakecamp.com/phantom_lake↗).

Dedication

This book is dedicated to 1) the hydrogeology students whose questions led to the initiation of this glossary and 2) the authors from a wide variety of disciplines who publish papers relating to groundwater and bring new ideas and terms to our attention.

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The Groundwater Project Foreword

At the United Nations (UN) Water Summit held on December 2022, delegates agreed that statements from all major groundwater-related events will be unified in 2023 into one comprehensive groundwater message. This message will be released at the UN 2023 Water Conference, a landmark event that will bring attention at the highest international level to the importance of groundwater for the future of humanity and ecosystems. This message will bring clarity to groundwater issues to advance understanding globally of the challenges faced and actions needed to resolve the world's groundwater problems. Groundwater education is key.

The 2023 World Water Day theme *Accelerating Change* is in sync with the goal of the Groundwater Project (GW-Project). The GW-Project is a registered Canadian charity founded in 2018 and committed to the advancement of groundwater education as a means to accelerate action related to our essential groundwater resources. To this end, we create and disseminate knowledge through a unique approach: the democratization of groundwater knowledge. We act on this principle through our website gw-project.org/↗, a global platform, based on the principle that:

"Knowledge should be free, and the best knowledge should be free knowledge." Anonymous

The mission of the GW-Project is to promote groundwater learning across the globe. This is accomplished by providing accessible, engaging, and high-quality educational materials—free-of-charge online and in many languages—to all who want to learn about groundwater. In short, the GW-Project provides essential knowledge and tools needed to develop groundwater sustainably for the future of humanity and ecosystems. This is a new type of global educational endeavor that is made possible through the contributions of a dedicated international group of volunteer professionals from diverse disciplines. Academics, consultants, and retirees contribute by writing and/or reviewing the books aimed at diverse levels of readers from children to high school, undergraduate and graduate students, or professionals in the groundwater field. More than 1,000 dedicated volunteers from 127 countries and six continents are involved—and participation is growing.

Hundreds of books will be published online over the coming years, first in English and then in other languages. An important tenet of GW-Project books is a strong emphasis on visualization; with clear illustrations to stimulate spatial and critical thinking. In future, the publications will also include videos and other dynamic learning tools. Revised editions of the books are published from time to time. Users are invited to propose revisions.

We thank you for being part of the GW-Project Community. We hope to hear from you about your experience with the project materials, and welcome ideas and volunteers!

The GW-Project Board of Directors, January 2023

Foreword

A Glossary of Hydrogeology is more than what the title implies as its scope ranges far beyond that which is commonly regarded as hydrogeology. Further, its emphasis is squarely on education, thus it ranges farther than the bare definition of terms to include comprehensive explanations that help the reader gain a clearer and deeper understanding.

This unique glossary defines key terms that cut across professions and builds a foundation for sharing knowledge—the cornerstone of scientific collaboration and education. More than 2,000 terms are included, covering nearly all the vocabulary that pertains to water, including the methods used to investigate water on land and below the land surface. Additionally, this glossary covers the physical, chemical, and biochemical aspects of other sciences where water is relevant.

Where equations are referred to by name, the equation is presented in its common mathematical form. For a term that represents a concept, a labeled figure is usually provided to enhance the reader's understanding.

This glossary is the first publication of its kind to reflect the multidisciplinary scope of groundwater science and is an innovation that originated from the long teaching and research career of the author, John (Jack) Sharp, emeritus professor at The University of Texas, Austin, USA.

John Cherry, The Groundwater Project Leader

Guelph, Ontario, Canada, September 2023

Preface

This glossary was initially prepared for students in hydrogeology classes at The University of Texas who were concerned about what key terms they should know. The glossary continues to expand as the field of hydrogeology grows and as other areas of hydrology, geology, engineering, biology, public administration, law, economics, and so on publish papers related to groundwater.

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  and
- Barry Hibbs, Professor, The California State University, Los Angeles, California, USA.

This glossary is intended to assist those interested in hydrogeology and exploring the vast and evolving hydrogeologic literature. I am grateful to Amanda Sills and the Formatting Team of the Groundwater Project for their oversight and copyediting of this book. I thank Eileen Poeter (Colorado School of Mines, Golden, Colorado, United States of America) for reviewing, editing, and producing this book.

1 Glossary

A

A-Horizon - the upper level of a soil that is characterized by a mixture of soil particles and organic matter; it is also the zone or layer of leaching of minerals and organic matter.

Absorption - see *sorption*.

Accuracy - the agreement (or lack of) between a measured value and an accepted reference or "true" value.

Acid-Base Reactions - chemical reactions that involve the exchange of one or more hydrogen ions, H^+, between neutral species (molecules, such as water, H_2O) or ions (e.g., NH_4^+, OH^-, or CO_3^{2-}).

Acidity - the number of bases in a molecule or the number of hydroxyl group ^-OH in a chemical equation. This is related to *pH*.

Acre-Foot - the volume of water that would cover an area of one acre (43,560 ft^2) to a depth of one foot; this is equal to 325,851 gallons or 1,233.48 m^3. One acre-foot can support the water needs of 1 or 2 urban households.

Acoustic Probe – water-level measuring device that uses sound waves.

Acrotelm - the upper layer of a peat bog where organic matter decomposes aerobically and much more rapidly than in the underlying, anaerobic catotelm.

Actinide - an element with an atomic number equal or greater than thorium (^{90}Th).

Adhesion - the attraction of water molecules to solid surfaces.

Activity - the value that represents effective concentration of a solute.

Adhesion - molecular attraction between the surfaces of two bodies in contact.

Adiabatic - any process or change in which heat does not enter or leave the system.

Adsorption - see *sorption*.

Advection - the transport of dissolved constituents (i.e., solutes), particulate and colloidal matter, particulate/colloidal matter, and/or heat by the bulk motion of flowing fluid (e.g., flowing groundwater). Advection is commonly considered synonymous with *forced convection* but care should be taken when dealing with variable density fluids.

Advection-Dispersion Equation -

$$\frac{\partial C}{\partial t} = \nabla(D'\nabla C) - \nabla(v \cdot C)$$

where:

C = chemical concentration (ML^{-3})

D' = coefficient of hydrodynamic dispersion (L^2T^{-1})

v = average linear velocity (LT^{-1})

Aeration - increasing the amount of air in a porous medium or in water.

Aerobic - biochemical processes that require the presence of oxygen.

Aeolian (Eolian) – windblown; carried and deposited by wind.

Aerobic - bacteria or processes active only in the presence of molecular oxygen.

Aerosol - minute solid particles or liquid droplets that are transportable by wind or atmospheric turbulence.

Aggregate - hard materials (e.g., sand, gravel, and crushed rock) that are used in cement, mortar, and asphalt or as roadbed material.

Aggressive (water) - water that corrodes anthropogenic and/or geological materials.

Alkaline - the condition of a water or soil that contains sufficient alkali substances (These generally contain hydroxyl groups, which on dissociation in water produce OH^{-1}, hydroxide ions) to raise the pH above 7.0.

Albedo - a measure of the reflectivity of a surface (e.g., an albedo of 50 means that the surface reflects 50 percent of the incoming radiation).

Alger-Harrison Method - estimates water salinity from resistivity well logs, comparing deep and shallow resistivity logs (Alger & Harrison, 1989).

Aliquot - one of a number of portions of water being analyzed.

Alkali Flat- a level area or plain in an arid or semiarid region, encrusted with alkali salts (e.g., calcium carbonates, gypsum, halite, etc.) that become concentrated by evaporation and poor drainage.

Alkane - a hydrocarbon (i.e., containing only carbon and hydrogen atoms) in which the carbon atoms are held together by single bonds (e.g., methane, ethane, propane, and so on).

Alkene - an unsaturated hydrocarbon compound with at least one carbon-to-carbon double bond (e.g., ethylene, propylene, and so on).

Alkyne - a hydrocarbon that contains a carbon-carbon triple bond (e.g., ethyne).

Allocation - assignment of permissible use rate for a resource; allocation can be made on a discharge rate basis (e.g., cfs, cubic feet per second), and should be equitable and feasible.

Allochthonous/Allogenic - materials of foreign origin (e.g., cave sediments transported in through sinkholes). This is related to *autochthonous*.

Allogenic Recharge - recharge by surface water from higher elevations flowing through dolines or fractures over a karstic aquifer. This is related to *autogenic recharge*.

Alluvial - refers to unconsolidated recent gravels, sands, silts, and clays deposited by a stream or river.

Alluvial Fan - a fan-shaped deposit at the mouth of a mountain canyon where stream gradient abruptly drops. These are usually coarse-grained sediments.

Alluvial (Adobe) Flat - generally a narrow plain formed by sheet flood deposition of fine sandy clay or adobe brought down by an ephemeral stream, and having a smooth hard surface (when dry) usually unmarked by stream channels.

Alluvium - sediments deposited by or in conjunction with running water in rivers, streams, or sheetwash and in alluvial fans. Alluvium includes floodplain and stream-terrace deposits. It is usually a good medium for storage and transmission of water.

Ambient Monitoring - monitoring existing conditions in a groundwater system.

American Rule - the USA riparian doctrine of water law that permits landowners to draw from the underlying groundwater below or surface waters on their property subject to reasonable use.

Amphiphilic - a molecule having both hydrophobic (nonpolar) and hydrophilic (polar) parts.

Anaerobic - bacteria or processes active only in the absence of molecular oxygen.

Anastomoses - the earliest solutional openings in rocks along bedding planes that provide conduits for groundwater flow.

Anhydrous - containing no water.

Anion - a negatively charged ion.

Anisotropy - the directional variation of a property at a point (e.g., different permeability in the horizontal and vertical direction).

Annual Runoff Coefficient - the ratio of annual runoff to precipitation.

Annular Space or Annulus - the opening between an inner and outer cylindrical body, often used to describe the space between the well screen or drill pipe and the wall of the borehole.

Anoxic - conditions where O_2 is absent or present in very low concentrations. Anoxic water has less than 0.5 mg/L of dissolved O_2.

Anthropogenic (or Anthropic) - created, caused, or induced by human actions. For example, anthropogenic contamination of groundwater refers to contaminants in groundwater as a result of human activity.

Anthropogenic Stressors (of Groundwater-Dependent Ecosystems) - pressures or dynamics that impact ecosystem components or processes caused by human-associated activities including—but not limited to—introduction of non-native species, release of biological pathogens (e.g., viruses, parasites), recreation, pollution, climate change, and population growth.

Aperture (*b*) - the distance between the two surfaces of a fracture.

Effective Aperture - defined by Wilson and Witherspoon (1974) as shown in the following equation.

$$b_{eff} = \left(\frac{\sum_{i=1}^{n} \ell_i}{\sum_{i=1}^{n} \frac{\ell_i}{b_i{}^3}} \right)^{\frac{1}{3}}$$

where:

b_{eff} = effective aperture of a portion of a fracture comprised of n sections of length ℓ_i of aperture b_i

ℓ_i = length of a portion of the fracture with an aperture of b_i.

Hydraulic Aperture - a measure of the ability of a fracture to transmit fluids as calculated by the cubic law. This is generally best estimated by the geometric mean aperture over the area of the fracture.

Kinematic Aperture - the widest aperture or paleo-aperture that can be measured. This includes filled fractures and veins, which are *not* open when the measurements are made.

Mechanical Aperture - the arithmetic mean aperture along the length of the fracture.

Residual Aperture - the aperture at which the hydraulic aperture remains essentially constant as a fracture undergoes compression, even though the mechanical aperture may continue to decrease. Bridging across zones of greater aperture causes this difference.

Transport (Tracer) Aperture - aperture estimated by tracer breakthrough curves using the cubic law.

Apparent Resistivity - resistivity of a homogeneous and isotropic half-space that would produce the measured voltage difference for a given applied current. Typically reported in ohm-meters. Apparent resistivity is used in a number of geophysical and hydrogeological applications.

Applied Water - water delivered to a user; it does not include precipitation or losses in the distribution/transmission system. Also called delivered water.

Appropriation Doctrine - a legal system in which waters are appropriated by the state in the western USA. It follows the practice of "first in time, first in right" meaning that when water is scarce, users with the earliest appropriation get their full allotment before users with later appropriations get any water.

Aquatic - growing in, living in, associated with, or frequenting water.

Aqueous Solubility - the amount of material that will dissolve in water at standard temperature and pressure.

Aquiclude - a geologic material, stratum, or formation that contains water (i.e., has porosity) but does not transmit it (i.e., has zero or negligible permeability).

Aquifer -

1) a saturated (consolidated or unconsolidated) geologic unit (material, stratum, or formation) or set of connected units that yield water of suitable quality to wells or springs in economically usable amounts, or

2) a formation, group of formations, or part of a formation that yields water of suitable quality to wells or springs in economically usable amounts.

An aquifer is not

- just a water-bearing unit (nearly all shallow units contain some water, but they may not have sufficient porosity, recharge, permeability, or water quality to be an aquifer);

nor is an aquifer

- as has been used in the petroleum literature, a geologic unit that supplies fluids to a petroleum reservoir, either naturally or because of well production.

Alluvial Aquifer – an aquifer composed unconsolidated sand and gravel deposited by a stream or running water (e.g., alluvium).

Confined (or Artesian) Aquifer - an aquifer that is immediately overlain by a low-permeability unit (confining layer). A confined aquifer does not have a water table.

Consolidated Aquifer - an aquifer consisting of rock that has undergone solidification or lithification (e.g., sandstone, limestone, and crystalline rocks).

Exempted Aquifer - an aquifer or its portion that meets the criteria in the definition of *underground source of drinking water* but which has been exempted according to the procedures of US Environmental Protection Agency (US EPA) (40 CFR§144.7), for use in energy, mining, and other companies for oil or mineral extraction or disposal purposes.

Leaky Aquifer - an aquifer that receives recharge via cross-formational flow through confining layers.

Major Aquifer - an aquifer that provides large amounts of water or covers a large area. Large is a relative term; compare with minor aquifer.

Minor Aquifer - an aquifer that provides small amounts of water or covers a small area. Small is a relative term; compare with major aquifer.

Perched Aquifer - a local, unconfined aquifer at a higher elevation than the underlying and separated by a confining bed from (often regional) unconfined aquifer. An unsaturated zone is present between the two unconfined aquifers. Compare with semi-perched aquifer.

Principal Aquifer – a laterally extensive aquifer that provides water in large amounts.

Semiconfined Aquifer - an aquifer with properties intermediate between a confined and an unconfined aquifer. Synonymous with leaky aquifer.

Semi-perched Aquifer - a local, unconfined aquifer at a higher elevation than the underlying (often regional) aquifer, from which it is separated by a confining bed, but an underlying unsaturated zone is not present. Compare with perched aquifer.

Sole Source Aquifer - an aquifer that provides at least 50 percent of the drinking water to a specific (*affected*) area.

Unconfined (or Water-Table) Aquifer - the upper surface of the aquifer is the water table. Water-table aquifers are directly overlain by an unsaturated zone or a surface water body.

Unconsolidated Aquifer - an aquifer consisting of loose material, such as sand or glacial drift that has not undergone lithification (e.g., an alluvial aquifer).

Aquifer Size - classification of aquifers based upon areal extent is shown in this table.

Aquifer size	Area (km^2)
Very small	< 100
Small	100–500
Medium-sized	500–5,000
Large	5,000–50,000
Very large	> 50,000

Aquifer System -

1) intercalated permeable and poorly permeable materials that comprise two or more permeable units separated by aquitards that impede vertical groundwater movement but do not affect the regional hydraulic continuity of the system, or
2) a series of two or more aquifers in continuous strata that have separate groundwater basins separated by groundwater divides or effluent streams. These aquifers may not be hydraulically connected or they have weak or intermittent hydraulic connections.

Aquifer Vulnerability Index (AVI) – an assessment of the vulnerability of an aquifer to contamination based upon the types and thicknesses of soils rocks between an aquifer and the ground surface (van Stempvroot et al, 1993).

Aquifuge - a geologic material, stratum, or formation that neither contains nor transmits water (i.e., has zero or negligible permeability and porosity).

Aquitard - a geologic material, stratum, or formation of low permeability (a confining unit) that transmits significant amounts of water only at a regional scale or over geologic time.

Arable - having soil and topographic features suitable for agriculture.

Archie's Law - calculates the electrical resistivity of a saturated porous medium (R_t) as a function of porosity (ϕ) and the fluid resistivity (R_w). Resistivity is typically

given in ohm meters, or siemens meters, with dimensions (e.g., mass, length, time, and current) of $ML^3T^{-3}A^{-2}$.

$$R_t = a\,\phi^{-m}R_w$$

where:

a = tortuosity (or Winsauer) factor (dimensionless)

m = cementation exponent (dimensionless)

Area of Influence - the area around a well in which hydraulic heads are affected by pumping from or injection into the well.

Area of Review -

1) the area surrounding an injection well described according to the criteria set forth in US EPA §146.06 (related to *zone of endangering influence)* or,
2) in the case of an area permit, the project area plus a circumscribing area the width of which is either a quarter of a mile (402.336 m) or a number calculated according to the criteria set forth in §146.06.

Argillaceous - rocks or substances composed of clay, slate, or shale.

Aridity Index (AI) - the ratio of precipitation to potential evapotranspiration.

The UNESCO Aridity Index defines climate regimes as shown in the following table. The Budyko Aridity Ratio, is essentially the reciprocal of AI.

Climate regime	Aridity index (P/PET)	Global land area
hyperarid	< 0.03	7.5 %
arid	0.03–0.20	12.1 %
semi-arid	0.20–0.50	17.7 %
dry subhumid	0.50–0.65	9.9 %
humid	> 0.65	52.8 %

The AI is calculated as shown in the following equation.

$$AI = \frac{P}{ETp} \quad \text{or} \quad AI_m = \frac{P}{T+10}$$

where:

P = precipitation (L)

ET_p = potential evapotranspiration (L)

AI_m = De Maronne aridity for use where ET_p is not available and the mean annual temperature, T, is greater than minus 9.9 ºC.

Arrhenius Equation - the equation expressing the reaction rate constant (k) as a function of the temperature (T).

$$k = Ae^{-E_a/RT}$$

where:

k = reaction rate constant (–)

A = empirical constant (–)

E_a = activation energy, typically J/mole (ML^2T^{-2})

R = gas constant, 8.314 J/mole (ML^2T^{-2})

T = temperature, typically in °K (Θ)

Arroyo - an ephemeral stream bed in arid and semiarid areas typically with coarse bed-load sediments and steep channel walls.

Artesian - hydrostratigraphically confined. In common usage, this implies the existence of flowing wells. However, all flowing wells are not artesian nor do all artesian wells flow.

Artificial Recharge - recharge caused or induced by human design.

Aspect Ratio -

1) the ratio of height to horizontal distance of a convection cell, or
2) ratio of maximum to minimum cell dimensions in a numerical model grid.

Asperity - an irregularity on a fracture surface, typically a projection that decreases the aperture.

Aquifer Storage and Recovery (ASR) - the process where water is injected into an aquifer and stored before pumping it for use.

Attenuation - the process of reducing a quantity of solute or colloid in a groundwater system over time or space by chemical and/or physical processes.

Atterberg Limits - the water content of fine-grained soils relating to the state of the soil (i.e., solid, semi-solid, plastic, liquid).

Liquid Limit (LL) - the moisture content below which the soil no longer flows like a liquid.

Plastic Limit (PL) - the moisture content below which the soil can no longer be remolded without cracking.

Shrinkage Limit (SL) - the moisture content below which the soil no longer changes volume upon drying; any loss of moisture is compensated by the entry of air into the pores.

Attributes -

1) nonspatial data, usually alphanumeric, that are linked to a spatial element (e.g., points depicting well locations may be linked to attribute files containing data on stratigraphy, water levels, water chemistry, and so on), or
2) a measurable quantity or criterion that has a common interpretation and can indicate the level of achievement of goals or objectives.

Auger - rotary drilling tool, typically used in soils or poorly consolidated materials that removes cuttings from a borehole by mechanical means without the use of drilling fluid. Augers operate on the inclined plane or screw principle.

Autocorrelation Function - the cross-correlation of a signal with itself, or more precisely,

1) the function describing the probability of change of a parameter with distance, or
2) a measure of how well a signal matches a time-shifted version of itself as a function of the amount of time shift.

Autochthonous - materials formed in place or derived in place. This is related to *allochthonous*.

Autogenic Recharge - recharge that is derived from precipitation within the carbonate catchment. This is related to *allogenic recharge*.

Available Capacity (Available Moisture) - the amount of water held in soil that is available to plants.

Aven - a hole in the roof of a cave passage that may be either a rather large blind roof pocket or a tributary inlet shaft into the cave system.

Average Linear Velocity - the specific discharge (Darcian velocity) divided by the effective porosity. The average linear velocity is an estimate of the mean rate that water molecules flow. Sometimes called the *effective velocity* or *average interstitial velocity*.

B

B-Horizon - horizon of illuviation in a soil profile characterized by the accumulation of iron oxides, clay minerals, calcite, and so on.

Backbone - the system of hydraulically connected fractures that dominate the flow and transport processes in a particular groundwater system.

Background Concentration – the concentration of a substance in water or another particular environment that has been minimally affected by anthropogenic (human) activities

Baffle - a barrier that diverts or deflects flowing water or groundwater. In the latter case, it may correspond to lenses of fine-grained sediments.

Bail (or Bail-Down) Test - a test of media hydraulic properties (typically, permeability and storativity) in which a volume of water is withdrawn instantaneously (bailed) from a well or piezometer and water level recovery is measured and analyzed. This is related to *slug test*.

Bailer - a (usually cylindrical) device for withdrawing or collecting water from a well or borehole.

Bajada – a broad alluvial slope extending from the base of a mountain range [or high escarpment] out into a basin and formed by coalescence of separate alluvial fans.

Balneology - the science of baths or bathing, especially the study of the therapeutic use of mineral baths.

Bankful Discharge - the stage or discharge of a river at which it reaches the channel capacity.

Bank Storage - water in an alluvial system that was recharged by the adjacent stream during the rising limb of a streamflow hydrograph.

Barometric Efficiency (BE) - the degree to which changes in hydraulic head in an aquifer or a well reflect changes in atmospheric pressure. This is related to *tidal efficiency (TE)*.

Barotropic - a fluid in which the surfaces of constant density or temperature are coincident with a surface of constant pressure.

Barrage - any artificial obstruction placed in water to raise the water level or divert flow.

Baseflow (Base Flow) -

1) groundwater flow to a surface water body (lake, swamp, or stream), or
2) that portion of stream discharge that is derived either from groundwater flow or from drainage of lakes, swamps, or water sources other than the net rainfall that creates surface runoff/overland flow.

Baseflow Index (BFI) - ratio of long-term baseflow to total streamflow.

Baseflow Recession - the decline in stream discharge when the stream is fed only by baseflow. Baseflow recessions are commonly exponential.

Base Level - the elevation to which topography will eventually be eroded by running water.

Baseline - a set of initial or critical observations or data used for comparison and control.

Basin -

1) an aquifer or aquifer system with boundaries defined by surface-water divides (topographic barriers), or
2) a structural basin in which the aquifers are isolated from adjacent aquifers, or
3) a geographical region drained by a network of rivers and/or streams.

Closed Basin - a basin, usually in an arid region, having no surface or subsurface drainage outlet. Discharge occurs only by evapotranspiration.

Basis Function - the interpolation function used to define a primary variable (e.g., head) in a finite-element model.

Becquerel - a unit of radiation: one disintegration per second.

Bed Material - the sediment composing the bottom of a streambed, lake, pond, river, or estuary.

Bedding Plane - the surface between two layers of sedimentary rock.

Bedrock - consolidated rock underlying soil and/or unconsolidated surficial material at the Earth's surface.

Beneficial Use - use of water with reasonable intelligence and diligence for a stated purpose. This includes conserved water. Beneficial usages include:

1) domestic and municipal;
2) industrial;
3) mining;
4) irrigation, livestock, and aquaculture;
5) hydropower;
6) navigation;
7) recreation; and
8) fish-and-wildlife habitat.

Benford's Law - the law of anomalous numbers, or the first-digit law, that describes the relative frequency distribution for leading digits of numbers in datasets. In many data sets (e.g., fracture porosity in granitic rocks), the leading digit is likely to be small and smaller values occur more frequently than larger values. The Law states that approximately 30 percent of numbers start with a 1 while less than 5 percent start with a 9.

Berm - a mound or ridge of soil that is used for a dam, impoundment, or barrier.

Bernoulli Equation - the total energy of an incompressible fluid is constant at all points along a flow path in a closed system.

$$E = gz + \frac{p}{\rho_f} + \frac{v^2}{2} + I$$

where:

E = total energy (ML^2T^{-2})

g = gravitational acceleration (LT^{-2})

z = elevation above a datum (L)

p = fluid pressure ($ML^{-1}T^{-2}$)

ρ_f = fluid density (ML^3)

v = fluid velocity (LT^{-1}), and

I = fluid internal energy (ML^2T^{-2}).

BHT (Bottom-Hole Temperature) - a temperature measured in a borehole at its total depth.

Biochemical Oxygen Demand (BOD) - a measure of the quantity of dissolved oxygen, typically in mg/L, necessary for the decomposition of organic matter in water by organisms (chiefly bacteria).

Biodegradation -

1) generally, the transformation of a material to another material by organisms (commonly microbes), or
2) the degradation of contaminants as a result of microbiological activity, typically mediated by bacteria resident in the subsurface or perhaps added during bioremediation.

Biogenic - formed biologically by organisms or within organisms.

Biome - a region defined by similar climate and geology.

Bioremediation - the process by which microbes or other organisms remove contaminants from a groundwater system.

Extrinsic Bioremediation - a process in which microbes are added to the system.

Intrinsic Bioremediation – a process that relies on microbes already existing in the system.

Biosphere - the total assemblage of living organisms on the Earth.

Biot Mechanism - fluid is forced to participate in the solid's motion because of viscous friction and inertial coupling.

Biot Theory - general equations of motion for poroelastic materials.

Biota - the total assemblage of plants and animals in an area. The biota is the sum of the plant life (flora) and animal life (fauna).

Bioventing - pulling air through and extracting it from the vadose zone.

Black Alkali - sodium carbonate (salts) (Na_2CO_3).

Black's Law - in fractured aquifers, contaminants appear at places we do not expect them and faster than we predicted in places where we do expect them (Black, 1993).

Blackwater - wastewater from toilets, latrines, and privies and from sinks used for food preparation or disposal of chemical or biological substances.

Bladder Pump - a positive displacement pump using compressed gas for sampling groundwater.

Bluewater - water in rivers, streams, lakes, and aquifers used for domestic or irrigation purposes.

Biological Oxygen Demand (BOD) - the amount of oxygen needed to neutralize (oxidize) organic matter in water.

Bog - a swampy or marshy area that receives its water primarily from direct precipitation. These can be located in areas of groundwater discharge. Common usage is synonymous with *swamp*.

Bolson - an internally drained (closed), intermontane basin with two major land-form components: basin floor and piedmont slope. The former includes nearly level alluvial plains and playa-lake depressions. The latter comprises slopes of erosional origin adjoining the mountain fronts (pediments) and complex constructional surfaces (bajadas) mainly composed of individual and/or coalescent alluvial fans.

Borehole - a hole drilled into the earth in which well casings or piezometers may be installed.

Boundary Condition - specified conditions at the edges or surfaces of a groundwater system. There are three basic types of boundary conditions (Cauchy, Dirichlet, and Neumann), plus some subvariants:

Dirichlet (or Type I) Boundary Condition - constant head or specified varying head for a given time at the boundary.

$$(\text{i.e.}, h(x,y,z,t) = h_{specified})$$

Neumann (or Type II) Boundary Condition - constant hydraulic gradient or specified varying hydraulic gradient for a given time at the boundary.

$$\left(\text{i.e.}, \frac{\partial h(x,y,z)}{\partial n} = \text{constant}\right)$$

where:

n = a distance normal to the boundary

Robin (or Type III) Boundary Condition - a weighted combination of Type I (Dirchlet) and Type II (Neumann) boundary conditions (i.e., a weighted combination of specified head and specified hydraulic gradient conditions).

$$(\text{i.e., } \mathrm{A} \cdot \mathrm{h(x,y,z,t)} + \mathrm{B} \cdot \frac{\partial h(x,y,z,t)}{\partial n} = \text{constant})$$

where:

n = normal to the boundary

A and B = weighting constants

Cauchy Boundary Condition - a head-dependent flux boundary, a special case of the Robin boundary condition where A=1 and B=1.

$$\left(\text{i.e., h(x, y, z, t)} + \frac{\partial h(x,y,z,t)}{\partial n} = \text{constant}\right)$$

where:

n = normal to the boundary

Mixed Boundary Condition - similar to the Robin boundary condition except that different portions of the boundary are specified by different conditions. For example, parts of the boundary might be a Dirichlet condition and other parts might be a Neumann condition, i.e., A=1 and B=0 or A=0 and B=1.

No-Flow Boundary Condition - a special case of the Neumann boundary condition where the gradient, thus flux, is zero. This can be caused by a zero-permeability boundary or a symmetry boundary (e.g., a groundwater divide).

Boussinesq Equation - general equation for one-dimensional, unconfined, transient flow, with hydraulic head equal to the height of the water table above an impermeable horizontal base.

Bowen Ratio (Factor) - the ratio between sensible and latent heat fluxes, Typical ratios are about 0.1 for oceans and 5.8 for deserts.

Brackish (Water) - water with a saltiness greater than fresh water and less than salt water. More specifically, water with a total dissolved solids (TDS) range of:

1) 1,000 to 10,000 mg/L or 1,000 to 10,000 ppm (Davis & DeWeist, 1967). This is the *preferred* (and simplest) definition.

Other definitions include (Hem, 1985; Stanton et al., 2017):

2) 500 to 1,600 ppm or 500 to 1,600 mg/L,
3) 1,500 to 15,000 mg/L or 1,500 to 15,000 ppm.

Breakdown - rubble and debris in a cave caused by collapse of the cave ceiling.

Breccia - a clastic deposit consisting of angular clasts (fragments), commonly embedded in finer material.

Brine -

1) water with a salinity > 10,000 mg/L—the *preferred* (and simplest) definition (Davis & DeWeist, 1967).
2) In Hem's (1985) classification, a brine has a salinity > 35,000 mg/L; or
3) a heavily mineralized or high saline water commonly containing heavy metals and organic contaminants.

Brooks and Corey Equation - a model for capillary pressure as a function of the degree of saturation in the vadose zone (Brooks & Corey, 1964).

Brownfields - abandoned commercial and industrial sites. Their redevelopment or expansion is complicated by potential environmental contamination.

Bubble Point - the fluid temperature, for a given air pressure, at which a vapor phase appears (i.e., at which gas bubbles spontaneously form in a liquid).

Budyko Aridity Ratio (BAR) - the ratio of mean annual precipitation to mean annual potential evapotranspiration. If BAR < 1, the region is wet; BAR > 1, the region is dry; and BAR > 2, the region is semiarid. This is related to *aridity index* and *Palmer Drought Severity Index*.

Bulk Modulus (of Elasticity) - the ratio of compressive (or tensile) stress applied to a substance to the change in volume of the substance per unit of original volume. This is related to *Young's modulus*.

Bulk Retention Capacity - the ratio of the combined volume of residual and pooled NAPL (Non-Aqueous Phase Liquid), commonly DNAPL (Dense Non-Aqueous Phase Liquid), to the volume of the subsurface where it migrated.

Buoyancy -

1) the tendency of a body or fluid to rise when immersed in fluid because of density differences, or
2) the resultant vertical force exerted on a body by the static fluid in which it is floating or submerged.

Buoyant Weight - the difference between the weight of an object and the weight of fluid that it displaces when floating or submerged.

Burial History Curve - an age-depth plot that traces the burial and tectonic history of a geological stratum from the time of deposition to the present.

Bypass Flow - water percolating through the unsaturated zone that flows through only a small fraction of the total porosity.

C

C-Horizon - unconsolidated material (the parent material) from which a soil forms. C-horizon materials are essentially unaltered by near surface pedogenic processes.

Cable Tool - a well drilling system that repeatedly raises and drops a heavy drill string with a chisel-like bit at the bottom.

Calcareous - containing 50 percent or more $CaCO_3$.

Calibration -

1) the establishment of an analytical curve relating instrument response to analyte amount or concentration, or
2) the adjusting of parameters of a model until model output matches field observations with some degree of accuracy.

Caliche - nodules or layers of calcium carbonate or other evaporite minerals in a soil, or below the soil zone, caused by mineral precipitation due to evaporation or transpiration of groundwater.

Caliper Log - a borehole log of the diameter of a borehole or uncased well.

Calorie - the amount of heat required to raise one gram (i.e., one cubic centimeter) of water 1 °K (which is the same as 1 °C). One calorie in chemistry ≅ 4.2 joules. One calorie on food packaging = 1,000 calories in chemistry.

Capacity Ratio - the ratio of mobile porosity (essentially the effective porosity or specific yield) and the immobile porosity (essentially the specific retention). The sum of the mobile and immobile porosities is the total porosity.

Capillarity - the action by which water is raised (or lowered) relative to the water table surface because of interaction between the water molecules and the solids of the porous medium. Capillarity can also refer to the movement of a fluid into a porous medium due to this interaction; this is also called *imbibition*.

Capillary Barrier – fine-grained lenses, layers, and laminations that resist penetration of the non-wetting fluid, such as a non-aqueous phase liquid (NAPL) or air in a water-wet system.

Capillary Fringe (or Zone) - the zone immediately above the water table where the medium is saturated or partially saturated by capillary rise from the phreatic zone. Water in the capillary fringe has a pressure less than atmospheric.

Capillary Number (N_{Ca}) - the product of fluid viscosity (μ) and fluid velocity (v) divided by surface tension (σ) or $N_{Ca} = (\mu v)/\sigma$.

Capillary Pressure - the pressure difference between the non-wetting fluid (e.g., LNAPL, oil, or air) and the wetting fluid (usually water). Capillary pressure is directly proportional to interfacial tension between the fluids and inversely proportional to the radius of curvature of the fluid-fluid interface.

Capillary Rise - the height above the water table (or any free water surface) to which water will rise because of capillarity.

Capture Zone - the part of an aquifer that contributes water to a pumping well.

Carbonates - sedimentary rocks composed of at least 50 percent carbonate minerals (calcite, aragonite, and dolomite) that are typically cemented.

Carbonaceous - relates chiefly to rocks or sediments consisting of or containing carbon or its compounds, including calcite ($CaCO_3$).

Carcinogen - any substance, radionuclide, or radiation that is an agent directly involved in the promotion of cancer or in the facilitation of propagation of cancer.

Carman-Kozeny Equation - an empirical relationship for the intrinsic permeability (k) as a function of, porosity (ϕ), specific surface area of matrix per unit volume of solid (M_s); c is a constant related to tortuosity. Also called the *Kozeny-Carman equation*.

$$k = c\ \frac{\phi^3}{(1-\phi)^2 M_s^2}$$

Casing - a pipe that is in a well or borehole. More specifically, a casing is a tubular, water-tight structure installed in an excavated or drilled hole to maintain the well opening and—along with cementing—confine the groundwater that may occur in multiple zones to their zone of origin, as well as prevent surface contaminants from entering the well.

Castile - a hill in carbonate formations (e.g., in the Permian Basin of Texas) formed by differential erosion because the castile units are dolomitized and more resistant to erosion than the surrounding limestones.

Catagenesis - the process by which organic material in sediments is thermally altered by increasing temperature. A temperature range of 50 to 200 °C is implied.

Catastrophic Collapse - the sudden and utter failure of overlying strata caused by removal of underlying materials.

Catchment - the area of land drained by a single stream or river or, in the case of karst, drained by a single doline or group of dolines. *Catchment*, *drainage basin*, and *watershed* are essentially equivalent terms.

Cation - a positively charged ion.

Cation-Exchange Capacity - the ability of a porous medium to sorb or hold cations (positively charged ions).

CATNIP - acronym for Cheapest Available Technology Not Involving Prosecution (instead of best practice) as coined by Price (1996).

Catotelm - the peat layer beneath the acrotelm that is permanently below the water table and under anaerobic conditions. Microbial activity and peat decomposition are very slow in the catotelm.

Cave -

1) a natural opening in a geologic medium that is large enough for human entry (diameter greater than 20 or, more generally, 50 cm) and with a length or depth of at least 10 m, or
2) a solutional opening that is greater than 5 to 15 mm in diameter or width, which is considered the effective aperture necessary for turbulent flow.

Active Cave - a cave that has a stream flowing within it.

Dead Cave - a cave without streams or drips of water.

Dry Cave - a cave without a running stream.

Flank Margin Cave - caves that develop on oceanic coasts at the mixing zone between a freshwater lens and the underlying marine water.

Phreatic Cave - a cave that occurs below the water table.

Slutch Cave – a cave formed by water flowing beneath the surface of peat deposits.

Vadose Cave - a cave that occurs above the water table.

Water-Table Cave - a cave that occurs at the approximate elevation of the water table.

Cave Fill - transported clastic material (gravel, sand, silt, and clay) covering the cave floor or completely, or partially, blocking the cave.

Cavern - a large underground opening.

Cavings - materials that erode (i.e., cave) from a borehole wall in response to upward-flowing fluid within the annulus of a well or borehole.

Cementation - the process by which clastic grains are joined together and the pore spaces are filled by precipitated minerals (e.g., calcite, silica, iron oxides).

Cementing - the operation where a cement slurry is pumped into a drilled hole and/or forced behind the casing.

Censored Data - data that are below the measurement or detection limit. This is related to *truncated data*.

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act. This is the Superfund Act enacted by the US Congress in 1980.

Cesspool - a *drywell* that receives untreated sanitary waste containing human excreta that sometimes has an open bottom and/or perforated sides.

Chalk - a soft, fine-grained limestone.

Change Point - times when change occurs in the probability distribution of a stochastic process or time series. Change Point Detection is the process of identifying those times.

Channeling - the flow of fluid along preferred paths in the plane of a fracture.

Chebotarev (1955) Sequence - the evolution of hydrochemical facies with a) travel along a flow path, b) increasing age of groundwater, or c) increasing depth of groundwater as shown in the following schematic. Also called the *Ignatovich-Souline Sequence*.

Travel along flow path ⟶

$HCO_3^- \rightarrow HCO_3^- + SO_4^{-2} \rightarrow SO_4^{-2} + HCO_3^- \rightarrow SO_4^{-2} + Cl^- \rightarrow Cl^- + SO_4^{-2} \rightarrow Cl^-$

$Ca^{+2} \rightarrow Mg^{+2} \rightarrow Na^+$

Increasing age/depth of groundwater ⟶

Check Dam - a small barrier constructed in a watercourse to decrease flow velocity, minimize channel scour, or promote deposition of sediment.

Chelation – the formation of complex ions with organic ligands.

Chemical Equilibria - the condition in which both the reactants and products of a chemical reaction are present in concentrations that have no further tendency to change with time.

Chemical Oxygen Demand (COD) - a measure of chemically oxidizable material in water. COD approximates the amount of organic matter and reducing material present in the water.

Chott - a salt lake in Africa that stays dry for much of the year but receives some water in the winter. Also called *shott* or *shatt*.

Cistern - a tank or pit that collects rainwater from the roof of a house or building.

Clathrate - a chemical compound in which a loose molecule one component is trapped inside a crystalline network of another component.

Clastic - a term describing sediments or rocks composed of mineral or rock fragments (e.g., sand, sandstone, shale, conglomerate) that are derived from pre-existing minerals or rocks and have been transported some distance from their places of origin.

Clausius-Clapeyron Equation -

1) calculates the increase of the water-holding capacity of the atmosphere by about 7% for every 1 °C (1.8 °F) rise in temperature.

2) {a more precise definition] specifies the temperature dependence of pressure, most importantly vapor pressure, at a discontinuous phase transition between two phases of matter of a single constituent.

Clay -

1) soil particles with < 0.002 mm effective diameter, or
2) a type of mineral, such as kaolinite, illite, or smectite.

Clean Water Act - legislation establishing administrative structure that regulates pollutant discharge into waters. For example, in the USA, the Environmental Protection Agency is given the authority to implement pollution control programs, including setting industrial wastewater standards.

Cleat - a vertical fracture in coal.

Clint - a limestone block that along with other clints form a pavement-like surface on limestone; the area and shape of clints depends upon the frequency and pattern of fissures called grikes or grykes.

Closed System - a system that allows energy—but not mass—to cross its borders (e.g., the Earth's hydrologic system).

Cloudburst - an extreme amount of precipitation delivered in a short period of time in a localized area and capable of creating flooding. Cloudbursts often occur in conjunction with thunderstorms.

Coarse-Grained – refers to a sediment or a clastic sedimentary rock whose particles have an average diameter of greater than 2 mm.

Coefficient of Curvature (C_C) - the ratio of d_{30}^2 / (d_{60} d_{10}). d is a grain size. The subscript on d indicates the percentage of soil (by weight) with grain sizes less than the value of d. C_C is an index of grain-size sorting.

Coefficient of Determination (R^2) - the percentage of variation of the dependent variable that is explainable by the regression line.

Coefficient of Hydrodynamic Dispersion (D') - the effective diffusion coefficient in a porous medium plus the product of average linear velocity and the dispersion length tensor.

Coefficient of Permeability - archaic term for hydraulic conductivity (K).

Coefficient of Storage - archaic term for storativity (S).

Coefficient of Transmissibility - archaic term for transmissivity (T).

Coefficient of Uniformity (C_u) - the ratio of d_{60} to d_{10} (the effective grain size). d is a grain size with the subscript indicating the percentage of soil (by weight) with grain sizes less than the value of d. C_u is an index of grain-size sorting. A soil with a uniformity of less than 2 is considered to have uniform sorting.

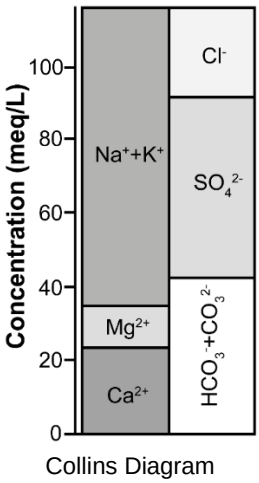
Coefficient of Variation (CV) - the standard deviation (σ) of a sample or population divided by the mean ($\bar{x}$).

$$CV = \frac{\sigma}{\bar{x}}$$

Coherence Function - a measure of the linear dependence of two signals as a function of frequency.

Coliform Bacteria - microbes (*Escherichia coli*) whose presence in groundwater indicates fecal contamination.

Collins Diagram - a split column with cation (left) and anion (right) proportioned concentrations in meq/L (milliequivalents per liter). The height for each analysis can be either variable (a measure of total meq/L) or a constant height only (reflecting the proportion of hydrochemical facies but not concentrations) as shown in the following figure.



Collins Diagram

Colloid - particles so small that they do not settle due to gravitational force, but are kept suspended by Brownian motion. For colloids in water, they range in size from 10^{-9} to 10^{-6} m (or 0.0001 to 1 microns).

Colloid Filtration Theory - a theory that predicts the continuum-scale colloid filtration rate coefficient (reflecting colloid retention) from pore scale mechanistic trajectory simulations that account for physicochemical processes governing colloid transport in an idealized representation of porous media. In colloid filtration, some colloids are filtered (retained) by the medium and unretained colloids are transported faster than the average pore-water velocity.

Colluvium- unconsolidated material deposited on and at the base of steep slopes by mass wasting (direct gravitational action) and local unconcentrated runoff.

Colmatage - when the transported particles are sieved by the solid porous medium fabric, decreasing the porosity, and possibly clogging the medium.

Comingling - the mixing, mingling, blending, or combining through the borehole casing, annulus, filter pack, and/or within the well (borehole) itself of water with different chemical quality.

Common Assessment Level - a single concentration threshold used to set and equal basis for comparing detection frequencies among various chemicals. Also called common detection limit.

Common Ion Effect - the decrease in solubility of a salt in water that already contains some ions of that salt when a soluble compound containing that salt is added to the water.

Common Ions (in Groundwater) - see *major ions*.

Compaction -

1) the processes by which sediment is densified (reduction of porosity or increase in bulk density) caused by an increase in the compressive stress (i.e., total stress). In soil mechanics, this term is limited to processes involving the expulsion of air from the voids. Or,
2) a densification process involving mechanical equipment, usually a roller.

Sometimes the terms compaction, compression, and consolidation are used interchangeably.

Complex -

1) a stable association of a metal ion with one or more ligands, or
2) a molecular entity formed by loose association involving two or more molecular entities (ionic or uncharged), or the corresponding species. The bonding between the components is generally weaker than a covalent bond. Also termed *coordination entity*.

Compressibility -

1) the capacity of a substance to be reduced in size by increasing pressure, or
2) the ratio of stress to strain; in a porous medium

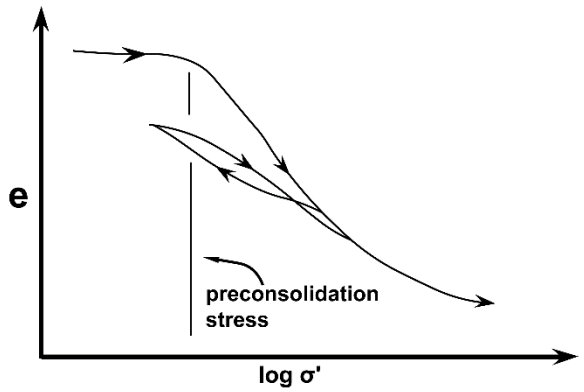
Aquifer thickness changes in response to changes in the effective stress. This is related to *bulk modulus* and *Young's modulus*.

Compression - the state where the forces are directed inward (or toward each other).

Compression (Consolidation) Index (C_c and C_a) - compression index is used with consolidation, there are two indices, primary and secondary.

Primary Compression Index (C_c) - slope of void ratio (e) versus the logarithm of effective stress (σ') as shown in the following equation and figure.

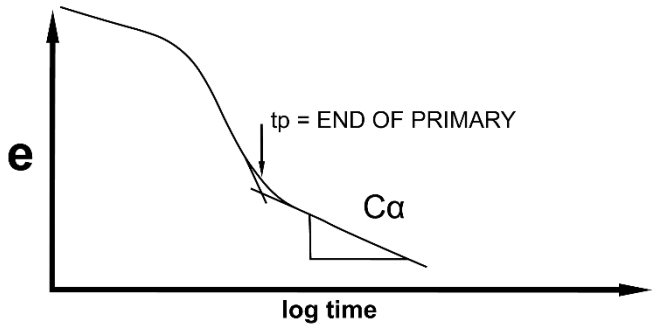
$$C_c = \frac{\Delta e}{\Delta \log(\sigma')}$$ while effective stress is increasing



Primary consolidation curve representing void ratio versus effective stress as a sample of porous material under compressed. The preconsolidation stress is indicated and the path of the relationship exhibits hysteresis during recovery and reconsolidation, indicating the material has undergone permanent change.

Secondary Compression Index (C_α) - slope of void ratio (e) versus the logarithm of time (t) curve after primary compression ceases (i.e., when effective stress remains constant) as shown in the following equation and figure.

$$C_\alpha = \frac{\Delta e}{\Delta \log(t)} \text{ after primary compression ceases}$$



Void ratio versus time for a sample of material under compression. t_p is the critical pressure where effective stress remains constant and secondary compression occurs.

Concentration - the amount of a dissolved or colloidal species in water. It is commonly given as:

1) mass of solute per mass of water, *molality* in ppm (parts per million) or epm (equivalent parts per million);
1) mass of solute per volume of water, *molarity* in mg/L (milligrams per liter) or meq/L (milligrams per equivalent parts per liter); or
2) mmol/L (millimoles per liter).

Flowing Concentration - the concentration measured in a flowing or pumping well or channel that averages a mixture of waters with varying concentrations.

In-Situ Concentration - the concentration at a point in the flow field.

Condensation - the process of a gas (or vapor) changing to its liquid form.

Conditional Simulation - simulation of one realization of a system with the temporal or spatial distribution of parameter values based on an estimate of the variance and trends of the values but with each realization conditioned to match measured values where data are available.

(Heat) Conduction - the process of heat transport from locations of higher temperature to locations of lower temperature caused by molecular movement.

Conductivity - see *hydraulic conductivity* and *thermal conductivity*.

Conduit - a natural or artificial channel or tube through which fluids can flow. Conduits can include

1) caves and solution channels in carbonate rocks; or
2) a high permeability pathway, most commonly associated with dissolution features (commonly considered to have a greater range than well scale and be visible to the naked eye); or
3) any open or closed channel for the conveyance of water; such as a pipe or culvert containing utility lines.

Cone of Depression - the depression of the water table or potentiometric surface that forms around a pumping well. Also called a *pumping cone*.

Confining Bed (or Unit) - a bed or layer of low-permeability material stratigraphically adjacent to (generally above but sometimes below) an aquifer. Confining beds include aquicludes, aquifuges, and aquitards.

Confining Layer - a layer or strata of low permeability overlying an aquifer. This is related to aquitard.

Composite Confining System – a multi-layered system of discontinuous (spatially-limited) barriers.

Confining Zone - a geological formation, group of formations, or part of a formation capable of limiting fluid movement above an injection zone.

Congener -

1) elements belonging to the same group on the periodic table (e.g., sodium and potassium are congeners) or,
2) a minor chemical constituent that gives water, wine, or liquor its distinctive character.

Conglomerate - coarse-grained, clastic rock composed of rounded to subangular rock fragments, (larger than 2 mm) commonly with a matrix of sand and finer material; cements include silica, calcium carbonate, and iron oxides. The consolidated equivalent of gravel.

Conjunctive Management - integrated management of two or more water resources, typically an aquifer and a surface water resource, that maximizes the net benefits from both sources over time.

Conjunctive Use - the coordinated use of surface water and groundwater (or any other water) resources.

Connate Water - water that is in the pores at the time of sediment deposition, derived from the Latin *con* (with) and *nate* (born). This term is now commonly used for water with long residence times that are not necessarily the "original" waters as per the original definition (Meinzer, 1923).

Consensus Yield - see *yield*.

Conservative Field - a vector field representing forces of physical systems in which energy is conserved. Groundwater flow systems are generally treated as conservative fields as energy loss by friction is ignored.

Conservative Species - a chemical species (e.g., Cl^-)that does not interact with, and is not retarded by, the solids of a porous medium.

Conserved Water - water saved by the holder of a water permit that could otherwise be lost to beneficial use and losses that would occur in the process of transporting and distributing the water.

Consolidation -

1) the reduction of porosity or increase in bulk density caused by an increase in effective stress, typically concomitant with a decrease in the fluid pressure and expulsion of water from the voids. This is primary consolidation. In some usages, consolidation is considered synonymous with lithification and compaction.

   Or,

2) any or all processes by which loose, soft, or liquid earth materials become firm and coherent.

Primary Consolidation - decrease in the void ratio (*e*) as a function of change in the effective stress (σ').

Secondary Consolidation -

1) decrease in the void ratio (*e*) as a function of time at a constant effective stress; or
2) continued deformation of the soil structure after excess pore pressure has dissipated, as small numbers of particles move at random shear strains, in a Poisson process, to new final positions; or
3) a *viscous* skeletal response that is sometimes called creep or a decrease in solid volume.

Chemical Consolidation – primary or secondary decrease in void ratio caused by precipitation of quartz or other cements.

Consolidation Index - see *compression index*.

Constituent - a biological or chemical substance in biota, sediment, or water.

Consumptive use -

1) groundwater or surface water use in which the water does not return to local surface streams or aquifers because it is absorbed, evaporated, or transpired; or
2) combined amounts of water needed for transpiration by vegetation and for evaporation from adjacent soil, snow, or intercepted precipitation.

Contaminant - physical, chemical, biological, and radiological substances in water. The term implies that these substances are harmful and have been introduced by human actions. Contaminants include radionuclides, metals (e.g., lead), pathogens, organic and inorganic industrial products, salts, hydrocarbons, agricultural byproducts, and pharmaceuticals.

Contaminate - to introduce a substance into waters that would cause the concentration of that substance to exceed the maximum contaminant level (MCL). Also used as a noun synonymously with *contaminant*.

Continuity - fluid entering a representative elemental volume (REV) either equals the fluid leaving, or a change in fluid stored in the REV occurs.

(increased fluid mass stored) = (mass of fluid in) - (mass of fluid out)

Continuity Equation - the net excess of mass flux into or out of any infinitesimal representative elemental volume (REV) is exactly equal to the change per unit time of fluid density multiplied by the free volume (of that element).

$$Ss\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right) = \nabla\left(\underline{K}\nabla h\right)$$

where:

Ss = specific storage (L^{-1})

h = hydraulic head (L)

t = time (T)

K = the hydraulic conductivity (LT^{-1}).

The equation shows that changes of fluid mass in a REV are reflected by changes in hydraulic head.

Convection -

1) the total transport process of heat, solutes, and/or suspended matter involving both diffusion and advection when there is fluid flow (the classical definition), or
2) the transport of heat, solutes, or suspended matter by a moving fluid (a common definition, not including diffusion or hydrodynamic dispersion directly).

There are two basic types of convection: free and forced.

Free or Natural Convection - convection created by density (buoyancy) gradients. These can be caused by variations in water temperature, salinity, or suspended matter. This is related to the Rayleigh Number.

Forced Convection or Advection - convection created by an externally imposed force field, such as groundwater flow caused by differences in water pressure or elevation.

Mixed Convection - convection caused by both free and forced convection occurring simultaneously in a system.

Conveyance - systematic flow, or transfer of water, from one point to another. This includes instream-conveyance, water-distribution, and wastewater-collection systems.

Conveyance Loss - loss of water from a channel or pipe during water conveyance. This includes losses from seepage, leakage, and evapotranspiration.

Cooper-Jacob Method - a graphical method using semi-logarithmic paper and a shortened version of the Theis Equation for pumping tests in confined aquifers. This is applicable to distance drawdown, recovery, and time drawdown methods.

$$s(r,t) = \frac{2.3Q}{4\pi T}\log_{10}\left(\frac{2.25Tt}{r^2S}\right)$$

where:

$s(r,t)$ = drawdown as a function of r and t (L)

Q = pumping rate (L^3T^{-1})

T = transmissivity (L^2T^{-1})

r = distance from the pumping well (L)

S = the storativity (-)

t = the time since pumping commenced (T)

1) **Distance-drawdown method** (using Δs for one log cycle of distance, r) for which drawdowns are measured in two or more wells at the same time after pumping starts.

$$T = \frac{2.3Q}{2\pi\Delta s_{log-r}}$$

$$S = \frac{2.25Tt}{{r_0}^2}$$

where:

Δs_{log-r} = the difference in drawdown over one logarithmic cycle of distance, r (L)

r_o = the distance intercept for the straight-line extrapolation of the drawdown versus distance curve out to where $s = 0$ (L)

2) **Recovery method** (using Δs for one log cycle of time, t') for which the well is pumped for a time (t^*), then pumping stops and residual drawdown is measured as water level in the well rises (i.e., the well recovers).

$$T = \frac{2.3Q}{4\pi\Delta s_{\log-t'}}$$

where:

$\Delta s_{\log-t'}$ = the difference in residual drawdown over one logarithmic cycle of recovery time (L)

t' = $t - t^*$ (T)

Storativity (S) cannot be directly determined by this method.

3) **Time-drawdown method** (using Δs for one log cycle of time, t) for which drawdowns are measured at the same well at different times after pumping starts.

$$T = \frac{2.3\ Q}{4\pi\Delta s_{log-t}}$$

$$S = \frac{2.25Tt_0}{r^2}$$

where:

Δs_{log-t} = difference in drawdown over one logarithmic cycle of time (L)

t_o = the time intercept for the straight-line extrapolation of the drawdown versus time curve out to where $s = 0$ (T)

Coquina – a detrital limestone composed wholly or chiefly of mechanically sorted and water-transported fossil debris .

Corrasion - the eroding of bedrock or sediments by the mechanical action of water or wind agents.

Correlation Length - see *variogram*.

Correlative Rights - rights that are co-equal or that relate to one another so that water rights owners cannot extract or pump more water than their share (e.g., distributing irrigation water rights based upon the number of irrigable acres).

Cosolvent - a substance that enhances solubility (of contaminants) in water.

Covariance (COV) - the joint variation of two variables (X_{ij} and X_{ik}) about their common mean.

($\bar{X}_j$ and $\bar{X}_k$)

or

$$COV_{jk} = \frac{\sum_{i=1}^{n}(x_{ij} - \overline{x_j})(x_{ik} - \overline{x_k})}{n-1}$$

Cover Collapse - the collapse of unconsolidated cover (soil, regolith, residuum, or outwash) into underlying cavernous bedrock.

Crest -

1) top of a dam or spillway, or
2) the highest elevation reached by flood waters.

Critical Point of Water - the special mix of temperatures and pressures where the difference between water liquid and gas phases ceases to exist.

Critical Zone – the *"heterogeneous, near surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources"* (National Research Council, 2001, p. 2). This includes everything from the top of the tree canopy to groundwater.

Critical Stream Depletion Zone - a area close to a stream in which a pumping cone of depression will impact streamflow.

Crop Root Zone - the soil depth from which a mature crop extracts most of the water needed for transpiration.

Cross-Amplitude Function - an expression of how the input signal is reflected in the groundwater the system (e.g., the time lag between precipitation and water level change, the magnitude of water level change and the time required for dissipation of the change).

Cross-Correlation - a standard statistical method of estimating the degree to which two time series relate to one another.

Cross-Formational Flow - vertical groundwater flow from one hydrostratigraphic unit to another.

Cross-Spectrum Analysis - a statistical technique that determines the relationship between two time series as a function of frequency.

Cryosphere - the total assemblage of water as ice (ice caps, glaciers, ice in surface waters, and permafrost on the Earth.

Crystalline Rocks – igneous or metamorphic rocks consisting wholly of crystals or fragments of crystals (e.g., granite schist). Porosity and permeability in these rocks is controlled by fractures.

Cubic Law - the relationship between discharge through a fracture, or fracture transmissivity, as a function of the cube of the fracture aperture.

$$Q = \frac{\rho_f \, g}{\mu} \frac{b^3}{12} \, \nabla h$$

where:

Q = discharge through a fracture of aperture b and width or height of 1 unit (L^3T^{-1})

b = fracture aperture (L)

ρ_f = fluid density (ML^{-3})

g = gravitational acceleration (LT^{-2})

∇h = hydraulic gradient (-)

Cumulative Flow - the total flow or discharge over a period of time. Discharge can be constant or variable with time. Synonymous with *totalized flow*.

Curie - a unit of measurement of radioactive decay equal to $3.7x10^{10}$ disintegrations per second (Becquerels).

Curie Point Isotherm - the temperature at which minerals lose their magnetic property in the upper lithosphere.

Curvature - the curvature function describes the shape or curvature of the surface topography, which indirectly influences groundwater recharge.

- *Positive* curvature indicates the surface is upwardly convex.
- *Negative* curvature indicates the surface is upwardly concave.
- *Zero* value indicates the surface is flat.

Cutoff Wall - a low-permeability barrier or wall that limits flow of groundwater and/or contaminants.

Cutter - deep solution-widened discontinuities between limestone pinnacles at or just below the land surface.

Cuttings - the materials contained within the cylindrical volume of the well bore created by the cutting action of the drill bit. These are normally flushed out or bailed from the well or borehole.

D

Dalton's Law - in a mixture of non-reacting gases, the total pressure exerted is equal to the sum of the partial pressures of the individual gases if the independent gas alone occupied the entire volume of the original mixture at the same temperature.

Damage - the weakening of a material caused by cracking, defects, and/or grain-size reduction.

Damkoehler Numbers (N_{daI} and N_{DaII}) - the two chemical Damkoehler numbers reflect relative rates of reaction and transport. N_{daI} is the ratio of the chemical reaction rate to the bulk mass flow rate; N_{DaII} is the ratio of the chemical reaction rate to the molecular diffusion rate.

Darcy (*d*) - a unit of intrinsic permeability that is proportional to a discharge of one cc/sec (cubic centimeter per second) of a fluid of one centipoise viscosity though an area of one cm^2 normal to a gradient of one atmosphere of pressure per centimeter. One darcy = 9.87×10^{-13} m^2.

Darcy's Law - the discharge of water (Q) through a unit area of porous medium is directly proportional to the hydraulic gradient (i) normal to that area (A). The constant of proportionality is the hydraulic conductivity (K).

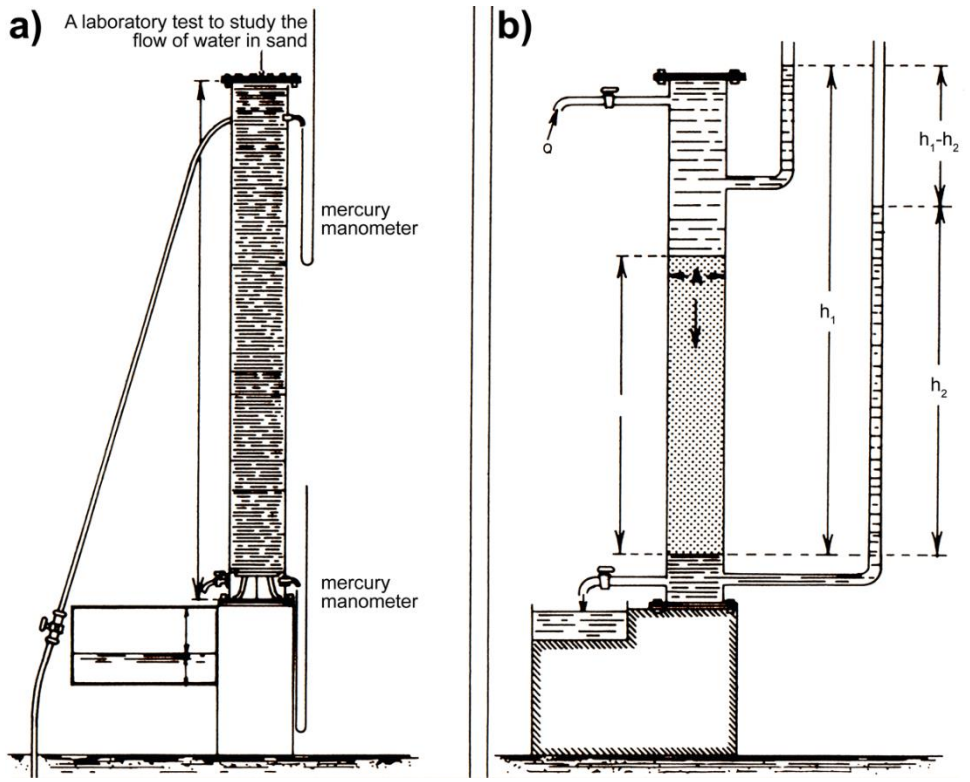
$$Q = KiA$$

Darcy Number (N_{Da}) - the ratio of a porous medium's intrinsic permeability (k) and its cross-sectional area, commonly expressed as a characteristic length (d) such as particle diameter squared.

$$N_{Da} = \frac{k}{d^2}$$

Darcian Velocity (q) - the discharge through an area of porous medium divided by that area. Also called specific discharge (LT^{-1}). It is equal to the discharge (Q) divided by the area normal to the discharge (A) ($q = {}^{Q}/_{A}$). The preferred term is *specific discharge.*

Darcy Tube - an apparatus used to test Darcy's Law and estimate hydraulic conductivity, as illustrated in the following figure.



Darcy tube diagrams: a) Darcy's (1856) sketch of his experimental apparatus and b) simplification by Hubbert (1969). The area and length of the sample, difference in head between the ends of the sample, and the flow rate are measured to calculate *K*.

Datum Plane - an arbitrary surface (or plane) used in measurement of hydraulic head, commonly *mean sea level*.

Debris Flow (Mudflow) - a mass movement process (or the depositional product) involving rapid flowage of highly viscous mixtures of debris, water, and entrapped air. Water content may range up to 60%. A mudflow is a type of debris flow with clastic particles of sand size and finer

Decision Support System - an interactive computer model that incorporates all available data relative to a water resource problem and, through programmable analyses, assists with formulation and selection of appropriate management decisions.

Deflation - process by which a soil surface is lowered by windborne loss of material.

Deformation - A change in the original shape of a material.

Degeneracies - different combinations of parameters in a model that yield the same observable outcome (i.e., this indicates model calibration is nonunique).

Degradate – a compound formed by the transformation of a parent compound by abiotic or biotic processes.

Degradation - the natural breakdown of a material (usually a compound) into simpler materials (compounds and byproducts).

Delay Time - duration of time for a contaminant or water to move from a point of concern to a well or spring (analogous to time of travel).

Deliquescent - tending to melt or dissolve; especially tending to undergo gradual dissolution and liquefaction by the attraction and absorption of moisture from the air.

Dendritic (Drainage) Pattern - a pattern characterized by irregular branching in all directions like the pattern of tree branches.

Denitrification - bacterial reduction of dissolved nitrate to nitrogen gas.

Density (ρ) - the mass of a substance divided by its volume (ML^{-3}), usually the representative elementary volume (REV). The density of water generally increases with increasing fluid pressure, increasing concentration, and decreasing temperature.

Depression Storage - surface water collecting in small topographic depressions that is not part of overland flow.

Desalination - the process of removing salts from water.

Desertification - natural or anthropogenic processes that create landscapes of increased aridity.

Desired Future Conditions (DFC for Groundwater in Texas) - *"…the desired, quantified condition of groundwater resources (such as water levels, spring flows, or volumes) within a management area at one or more specified future times as defined by participating groundwater conservation districts within a groundwater management area as part of the joint planning process …"* (http://www.twdb.texas.gov/groundwater/dfc/index.asp).

Desorption - removal of absorbed or adsorbed substances from surfaces. The opposite of sorption.

Developed Water - new water added to a stream or other water supply sources through artificial means.

Dew Point - the air temperature for a given fluid and air pressure at which a liquid phase condenses from a gas phase.

Diagenesis - the physical, chemical, and microbial processes that alter sediment from the time of their deposition until the onset of metamorphism.

Diagenetic (or Evolved) Water - water in which the chemical and isotopic characteristics have been altered during diagenesis.

Diastem - a depositional break in sedimentation of minor extent and presumed to represent a hiatus of minor duration.

Dielectric Constant - a measure of the polarizability of a material in an electric field.

Diffuse (Diffused) Surface Water - water that, in its natural state, occurs on the surface of the ground prior to its entry into a watercourse, lake, or pond.

Diffusion - the spread of a solute by molecular (Brownian) movement from zones of high concentration to zones of low concentration; sometimes termed molecular diffusion.

Back Diffusion - diffusion from the matrix or porous medium back into a fracture after the main pulse of solute has passed through the fracture.

Matrix Diffusion - diffusion caused by a concentration gradient between the actively flowing portions (commonly fractures) and the more stagnant portions of a flow system.

Diffusion Coefficient - the coefficient relating solute flux due to diffusion to the concentration gradient.

Apparent (or Effective) Diffusion Coefficient - the diffusion coefficient in a porous medium. This is generally less than the molecular diffusion coefficient in an open container of water because of porosity, tortuosity, or saturation factors.

Molecular Diffusion Coefficient - the diffusion coefficient of a solute in an open container of water.

Diffusion Length - distance over which a chemical species or colloid diffuses or spreads out over a period of time. It is estimated as the square root of the product of the diffusion coefficient (diffusivity) times time.

Diffusivity - the ratio of conductivity and storativity (L^2T^{-1}). Examples include thermal diffusivity (thermal conductivity/specific heat) and hydraulic diffusivity (hydraulic conductivity/specific storage).

Dimensionless Dissolution Capacity - the fraction of a gas that can be dissolved into an underlying brine.

Dimensionless Number - these ratios represent the relative magnitudes of various physical and chemical forces in nature. Examples include the Reynolds and Rayleigh Numbers that are used to index various thresholds. For instance, the Reynolds Number can be used to infer if fluid flow is laminar or turbulent.

Dipole Test - a pumping test in which a well is sectioned off by a packer or packers and fluid is pumped from one section of the well and into another section of the same well.

Discharge -

1) the volumetric flow rate (L^3T^{-1}) of a stream, spring, or groundwater system; or
2) the water leaving a groundwater system by flow to surface water, to the land surface, or to the atmosphere.

Diffuse (non-point source) Discharge - occurs over a broad area (e.g., evapotranspiration from native plants or a crop).

Mean Discharge - arithmetic mean of discharges measured over a given period.

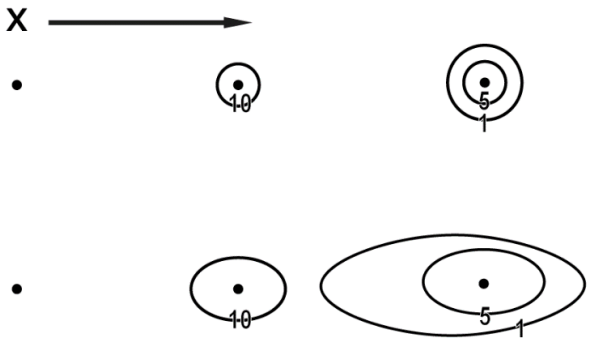
Instantaneous Discharge - discharge at a given instant of time.

Linear Discharge - discharge of a well divided by thickness of the producing interval.

Point Source Discharge - occurs in a limited closely defined area (e.g., spring orifices, well discharge).

Dispersion - the spread of solutes, colloids, particulate matter, or heat by the combined processes of diffusion and hydrodynamic dispersion.

Hydrodynamic Dispersion - the spread of solutes, colloids, or particulate matter by the physical mixing of fluids along the path of groundwater flow; sometimes termed mechanical dispersion.



Hydrodynamic dispersion spreads out and dilutes the solute as shown for a point source in this case, The direction of flow is from left to right as shown by the arrow. The upper progression of the plume shows advection and diffusion; the lower progression shows advection, diffusion, and dispersion.

Longitudinal Dispersion - dispersion parallel to the direction of groundwater flow.

Numerical Dispersion - the miscalculated spread of a solute (or other entity) due to overly coarse discretization of a numerical solution to the governing partial differential equations.

Taylor Dispersion - dispersion in laminar flow in a capillary tube, created by variable advection that is maximum in the center of the tube and near zero on the edges, along with diffusion normal to flow.

Thermal Dispersion - the spread of heat by the physical mixing of fluids along the path of groundwater flow.

Transverse Dispersion - dispersion perpendicular (normal) to the direction of groundwater flow.

Dispersion Coefficient - the sum of hydrodynamic (mechanical) dispersion and molecular diffusion in a porous medium.

Dispersion Length or Dispersivity - the factor that, when multiplied by the average linear velocity, estimates the coefficient of hydrodynamic dispersion, either longitudinal or transverse.

Dissolution (or Solution) - the process in which a solid or liquid becomes dissolved in (ground)water.

Congruent Dissolution - the products of dissolution are all dissolved species (i.e., solutes).

Incongruent Dissolution - one or more of the dissolution products is a mineral or amorphous solid.

Dissolved Load - the percentage of total stream load that is in solution.

Distance Drawdown Test - see *Cooper-Jacob Method*.

Distribution Coefficient - the measure of the tendency of a solute to sorb to the solid phase of a porous medium; more specifically, the mass of a solute sorbed per unit mass of solid divided by the solute mass dissolved in water per unit volume.

Distribution System - the system of ditches and conduits and their appurtenances that convey water from the main canal, or source, to its users.

Divide - a topographic high (or ridge) separating surface watersheds (catchments). A groundwater divide is an elevated area, line, or ridge; or a low area or valley of the potentiometric surface separating different groundwater flow systems.

DNAPL - a Dense (denser than water) Non-Aqueous Phase Liquid.

DNAPL Source Zone - the overall volume in the subsurface containing residual and/or pooled DNAPL (Dense Non-Aqueous Phase Liquid).

Doline - a closed topographic depression caused by dissolution or collapse of underlying rock or soil; synonymous with *sinkhole*.

Dolostone (**Dolomite**) - the sedimentary rock dolomite of which more than 50% by weight consists of the mineral *dolomite* [$CaMg(CO_3)_2$]. Dolostone can be used to avoid confusion with dolomite.

Domestic Use - water used by and connected to a household for purposes such as drinking, bathing, heating, cooking, sanitation, cleaning, and landscape irrigation. Ancillary use may include watering of domestic animals.

Double (or Dual) Porosity – a hydrogeological system with two porosities. An example is a porous rock with a fracture set. Such a system may then have two characteristic porosities: one for the fractures and one for the porous matrix. This term implies significant flow rates are present in both the fractures and the matrix.

Drainage Basin - the land area from which surface runoff drains into a stream system. This is related to *catchment* and *watershed*.

Drainage Density - the average length of streams per unit area of surface. It is an inverse function of soil permeability.

Drainage System - a surface stream or body of impounded surface water together with all surface streams and bodies of impounded water that are tributary to it.

DRASTIC – a basic method of assessing aquifer vulnerability to contamination based upon Depth to groundwater, Recharge rate, Aquifer type, Soil type, Topography, Impact of the vadose zone, and hydraulic Conductivity (Aller et al., 1987).

Drawdown - the drop in hydraulic head from the initial head caused by pumping from a well or set of wells.

Drill Stem -

1) in rotary drilling, the drill string, or
2) in cable tool drilling, a solid shaft or cylindrical bar attached to the drill bit to give it weight.

Drought -

1) a prolonged period of no or low (lower than average) precipitation, or
2) a climatic condition with insufficient soil moisture available for normal vegetative growth, or
3) a water scarcity arising from extended periods of below-normal precipitation, at times when and places where water use is demanded.

Agricultural Drought – occurs when crops become affected by drought.

Ecological Drought - an episodic deficit in water availability that drives ecosystems beyond vulnerability thresholds, impacts ecosystem services, and triggers feedback in natural and/or human systems.

Flash Drought -

1) the rapid onset or intensification of drought caused by some combination of low rates of precipitation and abnormally high temperatures, winds, and radiation; flash droughts can rapidly alter the local climate. Or,

2) an unusually rapid drought onset event characterized by a multi-week period of accelerated intensification that culminates in impacts to one or more sectors (e.g., agricultural, hydrological).

Hydrological Drought – occurs when low water supply becomes evident in the water system.

Meteorological Drought – occurs when dry weather patterns dominate an area.

Socioeconomic Drought - occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

Drought of Record - the worst recorded historical drought at a specific location.

Dryness Index - the ratio of potential evapotranspiration to precipitation.

Drywell - a well, other than an improved sinkhole or subsurface fluid distribution system, completed above the water table so that its bottom and sides are typically dry except when receiving fluids.

Dufour Effect - the flow of heat caused by a chemical gradient.

Dune - mound, ridge, or hill of loose, windblown granular material (generally sand), either bare or covered with vegetation.

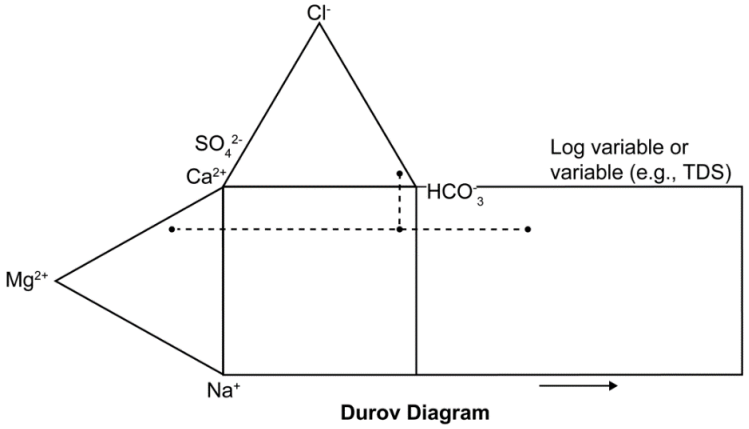
Durability - the resistance of aggregate particles to the accumulative effects of environmental and cyclical load conditions.

Dupuit Assumptions -

a) flow in an unconfined aquifer is horizontal and uniform,
b) the hydraulic gradient is equal to the slope of the water table, and
c) equipotentials are vertical.

Duration Curve - the percentage of time that flows of a stream are equaled or exceeded based upon a statistical study of historic streamflow records.

Durov Diagram - a graphical display using anion-cation hydrochemical facies, similar to a Piper Diagram, with a projection to a 4th dimension such as TDS or isotopic content.



Durov Diagram

A Durov Diagram with the sample value of relative proportions of major cations and anions on the triangular axes, which is then projected (dashed lines) onto the square and from there another variable (in this case TDS) is mapped (another dashed line) on the axis extending to the right. Each sample is assigned a symbol which is used at each of the 4 plotted points to facilitate connecting the chemical properties with a sample location/

Dust - dry, solid matter consisting of clay- and silt-size particles (< 62 μm) that are finely divided and can be readily lifted and transported by wind .

Dykstra-Parsons Coefficient (V_{DP}) - a coefficient used to compare the heterogeneity of a distribution, commonly permeability distributions. Small heterogeneity of a medium is indicated by $0 < V_{DP} < 0.5$. Extremely large heterogeneity of a medium is indicated by $0.7 < V_{DP} < 1.0$.

$$V_{DP} = \frac{k_{0.50} - k_{0.84}}{k_{0.50}}$$

where:

$k_{0.50}$ and $k_{0.84}$ = permeabilities of 0.50 (the mean) and 0.84 (84 percent of values are greater than this), respectively

Dynamic Equilibrium -

1) the condition in which head in a system does not change with time, but water is flowing in a steady (not stagnant) state, or in other words
2) the condition where the amount of groundwater recharge equals the amount of groundwater discharge.

Dynamic Yield - see *yield*.

E

Ebullition - a state of bubbling or boiling. Ebullition can fractionate isotopes in some hydrothermal/geothermal systems.

Ecohydrology - the study of the hydrologic mechanisms/processes that underlie ecological patterns and processes.

Ecological Laws - a suite of 27 laws proposed by Dansereau (1966). Those most relevant to hydrogeology are:

Law of the In-Optimum - in any given habitat, no species encounters the optimum conditions for all its functions.

Law of Aphasy - on average organic evolution is slower than environmental change, so migration occurs.

Law of Tolerance - a species is confined, ecologically and geographically, by the extremes of environmental adversities it can withstand.

Law of Persistence - many species, especially dominants of a community, are capable of surviving and maintaining their spatial position after their habitat and even the climate itself have ceased to favor full vitality.

Law of Factorial Control - although all living beings react holocoenotically (i.e., in concert) to all factors of the environmental in their particular conjunction, frequently there is a factor that has controlling power through its excess or deficiency.

Law of Irreversibility - some resources do not renew themselves because they are the result of a process that has ceased to function in a particular habitat or landscape at the present time.

Law of Domestication - species whose selection has been generally dominated by humanity are rarely able to survive without continued human protection.

Ecology - the study of the reaction of plants and animals to their immediate environment (i.e., habitat) and not their geographic location.

Ecosphere - the sum of the ecosystems of the Earth.

Ecosystem - a community of interdependent organisms living together in an environment.

Ecotone - a transition zone from one type of environment to another (e.g., playa to vegetated margins). Ecotones can occur abruptly of gradually.

Eddy Diffusion - diffusion that occurs in turbulent flow by the mixing of swirling eddies. This is important in streams and in atmospheric processes.

Effective Grain Size (d_{10}) - the grain-size below which 10 percent of the soil particles (by weight) are finer than that size.

Effective Porosity (ϕ_{eff}) - the porosity contributing to the flow of water (i.e., the interconnected porosity).

Effective Precipitation -

1) the portion of precipitation that produces runoff, or
2) the portion of precipitation falling on an irrigated area that is effective in meeting requirements of consumptive use.

Effective Solubility - the solubility calculated by Raoult's Law.

Effective Yield - see *yield*.

Efflorescence - the process involving upward capillarity that strands loose deposits of salt crystals at the soil surface.

Effluent -

1) wastewater or liquid waste from a sewage treatment or industrial plant, or
2) the property of receiving or draining water from another source (e.g., a gaining stream receives groundwater baseflow).

Eh - a measure of the oxidation-reduction state of a solution.

Electrical Conductivity (EC) - the ability of a material to conduct electricity. In water, EC is proportional to the salt (solute) concentration.

Electrical Permittivity - the measure of how much resistance is encountered when forming an electric field in a medium. Permittivity is determined by the ability of a material to polarize (i.e., separate its center of positive and negative charge in response to an electric field, and thereby reduce the total electric field inside the material. Thus, permittivity relates to a material's ability to transmit (or *permit*) an electric field.

Electro-Osmosis - flow of fluid caused by an electrical field.

Electron Acceptor and Electron Donor - a chemical entity that accepts electrons transferred to it from another chemical entity, which is an *electron donor*. Electron acceptors are oxidizing agents as they oxidize electron donors. By accepting electrons, electron acceptors are reduced (e.g., electron acceptors such as oxygen, nitrate, iron (III), manganese (IV), sulphate, and carbon dioxide are reduced by accepting electrons from donors such as hydrocarbon contaminants and are oxidized.

Electrophoresis - flow of ions caused by an electrical field.

Eluant - liquid used to remove dye from activated carbon packets (bugs) in tracer tests.

Elutant - the fluid (eluant and dissolved dye) used in the spectrofluorophotometer in trace tests.

Eluvial Horizon - a soil horizon from which material has been removed by the process of eluviation.

Eluviation - the removal of soil material in suspension (or in solution) from a layer or layers of soil by percolating water.

Emissivity - the measure of a material's ability to emit radiation; the ratio of energy radiated by a material to the amount of energy emitted by a black body at the same temperature.

Endorheic (Endoreic) - relating to a drainage basin or lake that normally has no outflow to other external bodies of water (e.g., Great Salt Lake, Lake Eyre, and the Dead and Caspian seas).

Endocrine Disrupting Chemicals (EDCs) - compounds that interfere with natural production, release, binding, action, or elimination of hormones in the body. These have entered groundwaters and surface waters through industrial pollution and, more significantly, disposal of sewage.

Endothermic - heat absorbing (e.g., a chemical reaction that requires heat to proceed).

Energy - the capacity for doing work.

Internal energy – energy associated to heat or chemical anergy in a piece of matter, commonly measured in calories.

Kinetic energy - energy associated with motion, generally measured as velocity

Potential energy - energy stored in a piece of matter at a given position, generally measured as elevation or head.

Enhanced Vegetation Index (EVI) - EVI quantifies greenery of vegetation. It is sensitive in areas with dense vegetation.

Enteric Viruses - a category of viruses related to human excreta.

Enthalpy - the heat content or sensible heat. **E**

Environmental Geology - geology concerned with Earth processes & resources, and engineering properties of Earth materials and relevant to:

1) protection of human health and natural ecosystems from adverse biochemical and/or geochemical reactions to naturally occurring chemicals or to chemicals or chemical compounds released into the environment by human activities, and
2) the protection of life, safety, and well-being of humans from natural processes, such as floods, hurricanes, earthquakes and landslides, through land-use planning.

Environmental Impact Statement (EIS) - a legal document describing the effect a project would have on a particular area or ecosystem.

Eolian - see aeolian.

Ephemeral Stream (or Spring) -

1) a stream (or spring) that flows only briefly in response to precipitation in the immediate area, or
2) a stream (or spring) that does not flow continuously for periods of greater than one month.

Epikarst (or Subcutaneous Zone) -

1) the interval between the A and B soil horizons and the main mass of relatively unweathered soluble bedrock,
2) soluble bedrock; part of the upper part of the karstic system and overlying soil that has a significant water storage capacity and preferred drainage pathway, or
3) the top of the karstified rock.

Epilimnion - the warmer, less dense top layer of water in a lake. This is related to *hypolimnion* and *thermocline*.

Epiphreatic - a flow system in karst where the conduits are sometimes partially filled with water but at other times are completely filled with water (in the phreatic zone).

Epistemology - the philosophical study of the nature of knowledge; epistemology is concerned with the scope of knowledge that encompasses and defines a specific discipline of study.

Epsom Salt - Magnesium sulfate ($MgSO_4$) which has been used for muscle relaxation.

Equilibrium Constant - the ratio between the amount (concentrations) of reactant and the amount (concentrations) of product in water containing a chemical reaction after sufficient time has elapsed for the chemical compositions to have no measurable tendency toward further change. The value of each rate constant is temperature dependent.

Equipotential (Φ) - a line or a surface composed of points having the same hydraulic potential or head.

Equipotential Line - a line on a map or cross section connecting points of equal hydraulic potential. The hydraulic gradient is normal to the equipotential line.

Equipotential Surface - a surface in a three-dimensional system connecting points of equal hydraulic potential. The hydraulic gradient is normal to the equipotential contours of the surface.

Erosion - the wearing down or washing away of soils and rocks at the land surface or the seafloor.

Estavelle - a surface orifice in a karstic system that, depending on weather conditions and season, can serve either as a sink or as a source of fresh water.

Eurythermal - tolerant of a wide range of temperatures. This is the opposite of *stenothermal*.

Eutrophic - having a large or excessive amount of plant nutrients, such as nitrates and phosphates. This is related to *oligotrophic*.

Eutrophication - the enrichment of water by nutrients (e.g., nitrogen and phosphorus).

Euxinic - a depositional environment of restricted circulation and stagnant or anaerobic conditions.

Evaporation - the process by which liquid water at or near the Earth's surface turns into vapor at temperatures less than the boiling point.

(Pan) Evaporation - evaporative losses from a standard evaporation pan.

Stage-1 Evaporation - the evaporative flux is from capillary liquid flow from the wet zone to the surface where liquid evaporation occurs.

Stage-2 Evaporation - the evaporation rate is limited by vapor diffusion through the porous medium to the evaporative surface.

Evaporite - a rock, or material, formed by the precipitation of minerals from evaporation of a body of water.

Evapotranspiration - the combination of evaporation and transpiration, generally measured as volume per time per area ($L^3T^{-1}L^{-2}$ which is LT^{-1}).

Actual Evapotranspiration (AET) - the amount of water that actually evaporates and transpires from a surface.

Potential Evapotranspiration (PET) - the amount of water that would evaporate and transpire from a surface if sufficient water was available to meet the demand. This is the uppermost rate of evapotranspiration for a well-watered crop.

Reference (Crop) Evapotranspiration - the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec m^{-1}, and an albedo of 0.23. This closely resembles the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground

surface. This term was introduced to avoid ambiguities in defining or estimating potential evapotranspiration.

Evasion - loss of dissolved gas to the atmosphere.

Exchange Capacity - see *cation exchange capacity*.

Exfiltration - leakage from a conveyance system or storage area into the surrounding materials.

Exorheic - open systems in which surface water flows through lakes, rivers, and other water bodies ultimately draining into the ocean.

Exothermic - heat liberating (e.g., a chemical reaction that releases heat).

External Cost - the cost of water production or consumption that must be borne by society and not the producer.

F

Facies – in stratigraphy,

1) the overall primary lithologic and paleontologic characteristics exhibited by a sedimentary rock and from which its origin and environment of formation may be inferred;
2) the general nature or appearance of a sedimentary rock produced under a given set of conditions that distinguishes one group from another within a stratigraphic unit. (e.g., contrasting river-channel facies and overbank-flood-plain facies in alluvial valley fills;

Fault - a fracture that has experienced translation or movement of the fracture walls parallel to the plane of the fracture.

Listric (growth) Fault - a fault with a curved fault plane usually with a steeply dipping section near the surface becoming increasingly flat with depth; called growth faults in the Gulf of Mexico Basin.

Normal Fault - a fault in which the hanging (upper) wall moves down with respect to the foot (lower) wall.

Reverse Fault - a fault in which the hanging (upper) wall moves up with respect to the foot (lower) wall.

Strike-Slip Fault - a fault in which movement in the plane of the fracture is parallel to the land (horizontal) surface.

Fault Scarp - the feature on the surface of the Earth that looks like a step caused by slip on the fault.

Fault Trace - The intersection of a fault with the ground surface; also, the line commonly plotted on geologic maps to represent a fault.

Fauna - the animal community of a given region.

Fen - a swampy or marshy area that receives its water primarily from groundwater discharge. Common usage is synonymous with *swamp*.

Fetch - the distance along a body of water over which the wind blows.

Fick's First Law of Diffusion - the diffusive flux per unit area is directly proportional to the concentration gradient.

$$\underline{J_c} = -D\nabla C$$

where:

$\underline{J_c}$ = chemical species flux per unit area, for example in moles per square centimeter per second (amount-of-substance $L^{-2}T^{-1}$)

D = coefficient of diffusion (L^2T^{-1})

∇C = chemical species concentration gradient (ML^{-3}).

Fick's Second Law of Diffusion - the rate of change of solute concentration is directly proportional to the divergence of the diffusive flux.

$$\frac{\partial C}{\partial t} = \nabla(D\nabla C)$$

where:

D = coefficient of diffusion (L^2T^{-1});

C = chemical species concentration (ML^{-3}); and

t = time (T).

Field Capacity - the amount of water a soil can hold under natural conditions by capillarity and the suction of plant roots. If the water content is greater than the field capacity, then gravity-driven downward flow occurs. Also called *field moisture capacity*.

Filtration - a process that physically removes particles from water.

Fine-Grained - a sediment or clastic sedimentary rock whose particles have an average diameter of less than 0.5 - 0.62 mm (i.e., less than sand size).

Finite-Difference Model - a computer approximation of a continuous (groundwater flow) system using a grid of cells, commonly the cells are rectangular prisms.

Finite-Element Model - a computer approximation of a continuous (groundwater flow) system as a mesh of polygonal elements.

Fissure - a long, narrow opening or line of breakage made by cracking or splitting of rock or soil, basically synonymous with *fracture*.

Filter Pack - coarse sand packed around the screen of a well.

Flocculation - the aggregation of particles (colloids or precipitates) suspended in a solution in order to attain a size at which they settle due to gravitational force. This is typically facilitated by adding a chemical coagulant.

Flood-

1) a relatively high rate of water flow measured by either stream-gage height or stream discharge,
2) an overflow or inundation from a river or other body of water that causes, or threatens, damage, or
3) to inundate or overflow.

Flood Flow - the stream discharge during periods of flood.

Flood Fringe - the part of the floodplain outside the flood way. It can be covered by shallow, slow flowing, flood waters.

Flood Peak - the highest stage or discharge during a given flood event.

Floodplain -

1) the low-lying (flat) areas adjacent to a stream that are occasionally, or are predicted to be, or have been covered by water when the stream overflows its banks, or
2) *(legal definition)* in some US states, the land adjoining lakes and rivers that is covered by the 100-year or regional flood.

Floodway - the land immediately adjoining a river that is the natural conduit for flood waters. It is part of the floodplain.

Flora - the plant community of a given region.

Flow - the rate of water discharge from a source or through an area expressed as a volume per unit time.

Flow Accumulation - is the sum of the weight of all cells that flow into a downslope cell in an output raster of a flow accumulation tool.

Flow Capacity -

1) the maximum amount of water any particular hydrogeologic environment can accept and transmit, or
2) the maximum amount of water an aquifer can transmit. This is related to *underfit basin*.

Flow Line/Flow Path - the path a packet of water takes in its movement through a porous medium.

Flow Net - a map showing both equipotentials and streamlines of groundwater flow in an aquifer or hydrogeologic system.

Flow Rate -

1) the discharge (or specific discharge) calculated by Darcy's Law, or
2) the fluid volume per time unit given for a gas or liquid that emerges from an orifice, pump, or turbine; moves through a pipe; or passes along a conduit or channel.

Flow Unit - (commonly used in petroleum geology, but this term should be avoided in that context) a permeable body of rock separated by low permeability surfaces or zones; a transmissive or permeable zone.

Fluffy Surface - composed of dry, easily wind-lofted salts supplied by capillarity and exemplary of playa environments.

Fluid - an aggregate of matter (liquid, vapor, or gas) in which the molecules are able to easily flow past each other without fracture planes forming.

Newtonian Fluid - a fluid (e.g., water) in which the absolute or dynamic viscosity (μ) does not change with the rate of deformation (i.e., the relationship between the shear stress and the rate of shear is linear, and μ is constant).

Experiments have shown that for a large class of fluids, the shear stress (τ) between any two thin sheets of fluid may be expressed as follows.

$$\tau = \mu \, du/dy$$

where:

τ = sheer stress ($ML^{-1}T^{-2}$)

du/dy = the velocity gradient, strain rate, deformation rate, or rate of shear (T^{-1})

μ = dynamic viscosity ($ML^{-1}T^{-1}$)

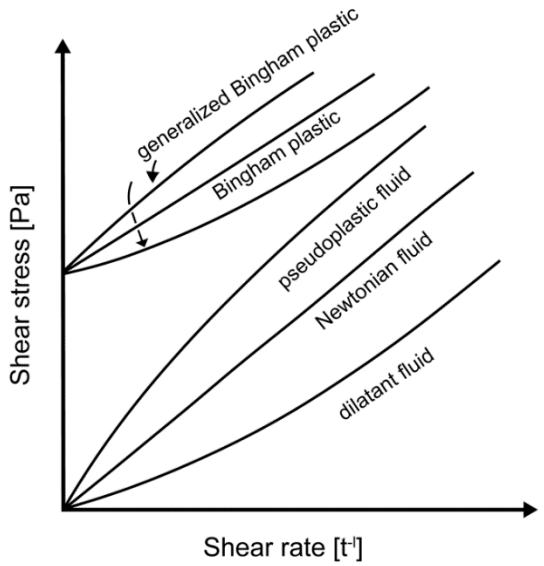
Non-Newtonian Fluid - a fluid where the viscosity (μ) varies with the rate of deformation. Non-Newtonian fluids include:

Bingham Plastic Fluids - These have a yield stress (i.e., the stress that must be exceeded before flow starts). Thereafter, the rate-of-shear curve is linear. If the flow curve thereafter yield is not linear, the fluid is called a *generalized Bingham plastic*.

Pseudoplastic or Thixotropic Fluids - These have no yield stress, but the viscosity falls progressively with shear rate (shear thinning). These fluids are used for oil drilling muds. Ketchup and honey are other examples of thixotropic fluids.

Dilatant or Rheopectic Fluids - also have no yield stress, but their viscosity increases with increasing rate of shear (shear thickening). Cream is an example of a rheopectic fluid, thus its consistency when whipped. Oobleck is an example of a dilatant fluid—a fluid similar to raw custard and made of cornstarch mixed with water. Unstressed, it behaves as a

liquid but applying a strong force makes it more viscous and it behaves much more like a solid, a fact that allows you to walk on it.



Shear stress versus shear rate for Newtonian and non-Newtonian fluids.

Fluvial - adjective for processes related to a river.

Fluvial Deposit - geological strata formed by the depositional activities of rivers.

Flux - the amount of flow (e.g., discharge of water) per unit area.

Darcy Flux - the rate of water flow normal to the hydraulic gradient (LT^{-1}). The quotient of volumetric flow and the area it pass through.

Footslope—General term for the lowermost erosional component of a hillslope geomorphic sequence (e.g., summit – shoulder – backslope - footslope - [depositional] toeslope.

Foramenular - (archaic) like a small opening, pore, orifice, or perforation.

Formation - a body of rock strata that consists of a certain lithology or combination of lithologies; a lithologically mappable unit.

"Fossil" Water - water that recharged an aquifer a very long time ago.

Fourier's Law of Heat Conduction - the conductive flux of heat per unit area is directly proportional to the temperature gradient, or

$$\underline{J} = -\underline{\lambda}\nabla T A$$

where:

$\underline{J}$ = heat flow, typically in watts (ML^2T^{-3})

λ = thermal conductivity, typically in watts per meter degree Kelvin ($MLT^{-3}\,\Theta^{-1}$)

A = cross sectional area, typically in square meters (L^2)

∇T = thermal gradient, typically in watts per meter ($\Theta\,L^{-1}$)

Fractal - a scale-invariant process, shape, or distribution. A power-law relationship between the number of objects (N) and their linear size (r).

$$N = C/r^D$$

where:

D = the fractal dimension ($1 < D < 2$ for a line and $2 < D < 3$ for a surface)

C = a constant

Self-Affine Fractal - a fractal in which different coordinates in the fractal are scaled by different factors. These fractals look different at different scales.

Self-Similar Fractal - a fractal that looks the same at all scales.

Fracture -

1) a sub-planar discontinuity in a rock or soil formed by mechanical stresses. A fracture is visible to the naked eye and is open (i.e., not filled with minerals). Fractures occluded by mineral precipitates are called veins. Microfractures are not visible to the naked eye. or,
2) a crack across which cohesion is lost, and that may be regarded as a surface (or plane) of discontinuity.

Fracture Anisotropy Factor (Ω_f) – an estimate of the fracture permeability anisotropy (not magnitude of the permeability).

$$\Omega_f = {}^{n_\theta}/_{n_L}$$

where:

n_θ = number of fracture length units of a given orientation

n_L = number of fracture length units within the petal of the rose diagram that contains the most fracture length units

Fracture Persistence - relates to the length of a fracture or its ability to extend through different units.

Fracture Skin - a coating of the fracture surface and/or the altered zone beneath the fracture surface that has different hydrogeological properties than the unaltered rock or sediment.

Fractured Formation - a fractured porous medium in which flow rates in the matrix can be assumed to be negligible. This is related to a *purely fractured medium* and a *double porosity medium*.

French Drain - an underground passageway for water through the interstices between stones loosely placed in a trench. This drain is named after Henry Flagg French, an American, not the country.

Fresh Water - water either with salinity < 1,000 mg/l or containing less than 250 mg/l dissolved chloride; drinkable, or potable, water is implied.

Friable - easily crumbled. Friable is used in description of soils and drill cuttings.

Froude Number (*Fr*) - the ratio of inertial force to gravitational force in flowing fluids; used to predict fluvial bedforms.

Fugacious - flying or disposed to fly, evanescent, volatile. The term is used by the Texas Supreme Court (USA) to describe "groundwater, which like oil and gas exists in subterranean reservoirs in which it is fugacious" (https://www.washburnlaw.edu/publications/wlj/online/volume/59/nation-pragmaticgroundwater.html↗).

Fugacity - the thermodynamic property that can be used as an analog to partial pressure when describing thermodynamics of natural systems. At a constant temperature, fugacity is proportional to the ratio of *chemical potential of the constituent of a system (e.g., oxygen in a magma)* to the *product of the gas constant (28.9625 g/mol) and temperature*.

Fumarole - a vent in or near a volcano (or magmatic activity) through which hot (often sulfurous) gases and vapors flow.

Fumigant - a volatile organic pesticide that is applied to soil to reduce populations of plant pests (nematodes, weeds, fungal pathogens and other soil-borne microbes).

G

Gage (alternate spelling: Gauge) Height - the water surface elevation relative to an arbitrary gauge datum.

Gaging (alternate spelling: Gauging) Station - a location on a stream, lake, or canal where data (usually stage/gage height) are collected. Stage is converted to discharge using a stage-discharge curve developed specifically for the location using field measurements of channel geometry and water velocity as a function of stage.

Gaining Stream - a stream that receives flow from the adjacent groundwater system. Same as *effluent stream*.

Ganat - see *qanat*.

Gas Hydrate - a form of ice with natural gas (mostly methane) trapped in the ice lattice. Gas hydrates are common in polar regions and, chiefly, oceanic sediments.

Gassman's Equations - a simplification of Biot's general equations of motion for poroelastic materials that are accurate only at lower frequencies in the 10 to 100 Hertz range.

Gate (as used in irrigation) - a structure or device for controlling the rate of flow from, or into, a canal or ditch.

Gated Pipe - a portable pipe with small gates installed along one side for delivering irrigation water to corrugations or furrows.

Gauge (alternative spelling: Gage) Height - the elevation of a water surface measured by a gauge.

Gauging (alternative spelling: Gaging) Station - a location on a stream, lake, or canal where data (usually stage/gage height) are collected. Stage is converted to discharge using a stage-discharge curve developed specifically for the location using measurements of channel geometry and water velocity, determined with an impeller, as a function of stage.

Genotype - an organism's full hereditary information as coded in the organism's DNA.

Geofluid - any fluid produced from a geothermal well; it may be dry, or superheated, steam; pressurized liquid; or a mixture of liquid and vapor. It is usually accompanied by dissolved solids and non-condensable gases.

Geogenic -

1) of or relating to the history of the Earth, or
2) resulting from geological processes.

Geogenic Constituents - chemicals or isotopes that have geologic or atmospheric sources. The constituent categories include: oxic waters, acidic waters, reducing waters. saline waters, radionuclides, pipe corrosion (not pipe leakage), and atmospheric (Erickson et al., 2024).

Geographic Information System (GIS) - a computer-based software package for storing, displaying, and querying location and attribute data.

Geography -The science that deals with the description, distribution, and interaction of the physical, biological, and cultural features of the Earth's surface**.**

Geohydrology -

1) the study of groundwater, emphasizing its hydrologic, rather than geologic, aspects (DeWeist, 1965, p.2), or
2) that branch of hydrology relating to subsurface or subterranean waters (Meinzer, 1942, p. 4).

The terms geohydrology, hydrogeology, and groundwater hydrology have often been used interchangeably, but some assign subtle distinctions such as geohydrology having a stronger hydrology emphasis, hydrogeology having a stronger geology emphasis, and groundwater hydrology having a stronger engineering emphasis.

Geology -

1) broadly, the study of the Earth (and other planetary bodies), or
2) (*legal definition* from the state of Wisconsin, USA) - a science that involves the study of the Earth and the Earth's origin, composition, structure, and physical history, including the study of natural agents, forces and, processes that cause changes in the Earth as well as the investigation and collection of data concerning the crust and interior of the Earth and the surface and underground gases, solids, and fluids that make up the Earth.

Geomatics - the science that deals with the collection, analysis, and interpretation of data about the Earth's land surface.

Geomorphic period - a period of landform/landscape development predominated by erosion over decades or centuries.

Geostatistics - statistics dealing with regionalized variables in geology.

Geothermal Gradient - the rate of increase in temperature per unit depth in the Earth. The geothermal gradient can vary both spatially and temporally, but averages ≈25 to 30 °C/km or ≈14 to 16 °F/1,000 ft.

Geothermal System - a hydrothermal system capable of generating electricity or heat for commercial purposes.

Geopressured, Geothermal System – a system in which hot fluids flow to the surface from over-pressured reservoirs at depth.

Hot-Dry Rock Hydrothermal System - systems with high thermal potential but limited formation water.

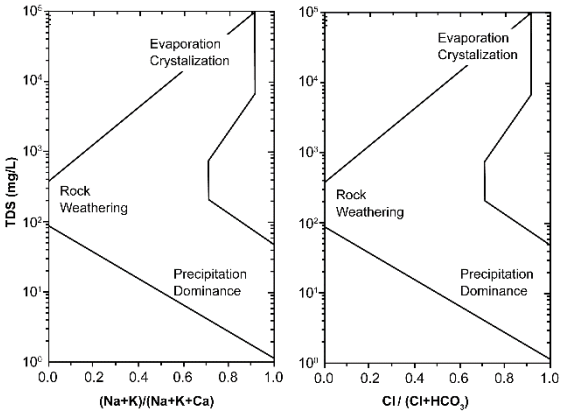
Hot-Water Dominated Hydrothermal System - systems in which the dominant water phase in the pores of the reservoir is liquid.

Vapor-Dominated Hydrothermal System - systems with "dry" steam; water in the pores of the reservoir is vapor and liquid.

Geyser - a periodic thermal spring that flows or spurts violently from discharge of super-heated steam or other gas.

Ghyben-Herzberg (or Freshwater) Lens - a body of flowing freshwater buoyantly overlying marine water.

Gibbs Diagram - plots water chemistry as the log of TDS (Total Dissolved Solvents) in mg/L or ppm as a function of cation (Na+K)/Na+K+Ca), and anion (Cl/(Cl+HCO_3) ratios to infer if the water chemistry is dominated by evaporation, crystallization, rock weathering, or recharge from precipitation (Gibbs, 1970).



Gibbs Diagram

Gilgai - a small ephemeral lake formed in a depression on expanding clay soil that creates small hummocks of swelling clays. Also, a term applied to the hummocks themselves.

Girinskii Potential - a specific discharge potential (Φ^G) for a stratified phreatic aquifer with essentially horizontal flow.

$$\Phi^G = \int_0^h \frac{\eth h}{\partial x} K(z) dz$$

where:

h = hydraulic head (L)

K = the hydraulic conductivity (LT^{-1})

z = vertical dimension, the direction normal to groundwater flow (L)

x = horizontal dimension, the direction of groundwater flow (L)

Glacial Drift - a general term for all material transported and deposited by glaciers and glacial meltwater.

Glairin – a mucilaginous organic substance that forms on the surface of some sulfur-bearing mineral waters. Also called baregin.

Glacier - a mass of land ice that flows downslope or outward.

Glauber's Salt - sodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$). It has been used as a laxative and for removal of excess drugs due to overdose.

Grab Sample - a sample taken at a particular place and time.

Gravel - soil or rock particles with an effective grain diameter between 2 and 64 mm.

Gravel Pack - gravel or sand used to fill the annulus between a well screen or casing and the rock or soil of the borehole wall.

Gravitational Water -

1) water in the zone of aeration (unsaturated zone) that can flow downwards by gravity, or
2) water in the zone of saturation that is not bound to the solid material.

Gravity Water - water that is transported from its source to its place of use by gravity, not by pumping. It refers to both groundwater and surface water.

Graywater (alternative spelling: Greywater) - wastewater from clothes washing machines, showers, bathtubs, handwashing, and sinks not used for disposal of food preparation materials, chemical, and/or biological substances.

Green-Ampt Equation - an equation, based upon Darcy's Law, to calculate the infiltration capacity (I_C) any time through unsaturated soil.

$$I_C = K_S + \frac{K_S S_W (\theta_S - \theta_i)}{F}$$

where:

I_C = infiltration capacity (LT^{-1})

K_S = effective hydraulic conductivity of the unsaturated zone (LT^{-1})

S_W = average soil water suction across the wetting front (L)

F = cumulative infiltration (L) at time *t*, the depth of the wetting front is $F/(\theta_S - \theta_i)$

θ_s = saturated volumetric moisture content (-)

θ_i = unsaturated volumetric moisture content (-)

Green water - water in the soil, or groundwater, from precipitation. It is sometimes considered synonymous with *soil water*.

Grike (alternative spelling: Gryke) - a vertical, or subvertical, fissure, crevice, or narrow gulley formed by dissolution and separating blocks, or clints, in a limestone pavement.

Bedding Grike - a narrow horizontal, or sub horizontal, slot in a karst outcrop caused by dissolution along a bedding plane.

Groundwater -

1) generally, all water beneath the land surface; or
2) sometimes, it is more narrowly defined as phreatic water (i.e., water beneath the water table) where the fluid pressure (p) is greater than atmospheric pressure ($P_{\text{atmospheric}}$).

$$(p \geq p_{\text{atmospheric}})$$

Basal Groundwater - the part of the freshwater lens that is underlain by sea water.

Parabasal Groundwater - groundwater in the freshwater lens that is hydraulically continuous with basal groundwater but underlain by (basement) rocks of low permeability.

Groundwater Age – the time elapsed since recharge water became isolated from the atmosphere.

Groundwater Availability - estimated sustainable available yield (i.e., effective recharge plus the amount of water recovered from storage over time without causing irreversible harm such as subsidence or water quality deterioration).

Groundwater Barrier - natural or emplaced material of relatively low permeability in the subsurface that impedes the flow of groundwater and generally causes a pronounced head difference on opposite sides of the barrier.

Groundwater Conservation District (GCD) - a local authority in the state of Texas, USA, dedicated to groundwater management. These are commonly associated with single county.

Groundwater-Dependent Ecosystems (GDE) - ecosystems located close to a groundwater discharge zone or the water table. These systems would decline or die if discharge ceases or the water table drops too much.

Groundwater Heat Pump - a means of controlling the temperature in buildings using the shallow groundwater as a heat source in the winter and as a heat sink in the summer.

Groundwater Mound - an area of elevated water table or potentiometric surface created by recharge.

Groundwater Residence Time - the average amount of time it takes from a point where water enters an aquifer until reaches a specific point of discharge.

Groundwater Sapping - geomorphic erosion process caused by concentrated groundwater discharge.

Growing Degree Days - a measure of heat accumulation used to predict plant (and animal) development rates, sometimes used as a surrogate for evapotranspiration.

Gryke (alternative spelling: Grike) – a vertical, or subvertical, fissure, crevice, or narrow gulley formed by dissolution and separating blocks, or clints, in a limestone pavement.

Gushet - a discrete spring flow gushing from a cliff wall of a perched, unconfined aquifer.

Gypsite - a partly indurated variety of gypsum commonly with clay to fine-sand impurities.

Gypsophiles - plants that grow only on soils rich in gypsum.

Gypsovags - plants that can grow either on or off gypsum-rich soils.

Gypsum - A widely distributed mineral consisting of aquated calcium sulfate: $CaSO_4.2H_2O$

H

Haboob - a strong storm front that lifts dust into the atmosphere as the storm front moves across the floor of a desert (e.g., the Sahara in northern Africa) or a plain (e.g., the High Plains of Texas, USA). Also called a *shamal*.

Habitat (of a Groundwater-Dependent Ecosystem) - location where a particular taxon of plant or animal lives and its surroundings, both abiotic and biotic. This includes the presence of the set of natural conditions surrounding the organisms (e.g., air, water, soil, mineral elements, moisture, temperature, topography).

Hail - precipitation in the form of spheres or lumps of ice.

Half-Life -

1) the time required for 50 percent of a radioactive element to decay; or
2) the time required for the concentration of a compound in a given setting to be reduced to one-half of its original value by one or more processes (e.g., biodegradation, radioactive decay, transport into another environmental medium).

Halite - sodium chloride (NaCl); common salt.

Halophyte - a plant that thrives in saline soils.

Hantush-Jacob Equation - an equation describing the drawdown (i.e., change in head) with time during pumping in a leaky aquifer.

$$s = \frac{Q}{4\pi T} W(u, r/\beta)$$

where:

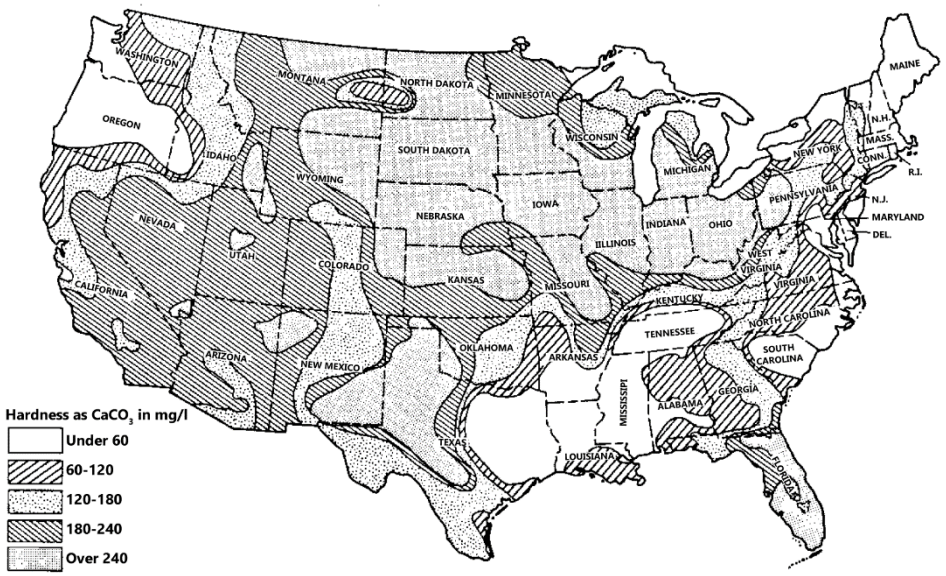
s = drawdown (L)
Q = pumping rate (L^3T^{-1})
T = transmissivity (L^2T^{-1})
$W(u, r/\beta)$ = leaky confined aquifer well function (-) where u is $r^2S/4Tt$
β = leakage factor $(Tb'/K')^{1/2}$
r = distance from the pumping well (L)
S = storativity (-)
t = time since pumping began (T)

b' = confining layer thickness (L)

K' = confining layer vertical hydraulic conductivity (LT^{-1})

Hardground - a layer of hardened chalk created by synsedimentary cementation in shallow waters. Synsedimentary means it forms within the sediment during sedimentation.

Hardness (of Water) - is the sum of the polyvalent ion equivalents, typically expressed as an equivalent concentration of $CaCO_3$. Water with higher values of hardness require more soap to produce a lather.



Hardness distribution in the continental United States.

Hardpan - a shallow layer in the soil that has become relatively hard and impermeable, typically caused by deposition of clays or carbonate (*caliché*).

Harm - a significant modification or degradation of a species' habitat, that either kills a member of the species or impairs its natural behavior as described in the US Endangered Species Act 16 U.S.C. 1531-1544 (US Fish and Wildlife Service (1973).

Hashin and Shtrikman Bounds - theoretical upper and lower limits for a parameter (e.g., thermal conductivity or diffusivity) for a three-dimensional assemblage of two components (e.g., sand grains and water).

Hazard - an agent or process of land change that can harm individuals, societies, or natural resources. Hazards can be sudden perturbations (e.g., landslides or floods) or slowly increasing stresses (e.g., subsidence or soil salinization) that exceed the normal range of natural system variability.

Hazardous Waste - waste that threatens living organisms because it contains toxic chemicals, is a fire hazard, is corrosive or caustic, may explode, reacts violently with water or air, generates toxic gases, is radioactive, or is biologically viral or otherwise detrimental to public health.

Hazen's Approximation - an empirical equation that estimates hydraulic conductivity as being linearly proportional to the square of the effective grain size (d_{10}).

Head or Hydraulic Head (h) - fluid mechanical energy per unit weight of fluid, which correlates to the elevation that water will rise to in a well (L).

Elevation Head -

1) head due to the energy that is the result of gravity (measured by the elevation of the water relative to some datum) or
2) a measure of hydrostatic fluid pressure above some reference point (datum).

Environmental Water Head - the sum of the elevation head and the pressure head calculated using the average density of the water over the whole water column, not just the screened interval. This is used for calculating the vertical hydraulic gradient and flow direction.

Fresh-Water Head or Equivalent Fresh-Water Head - the sum of the elevation head and the pressure head calculated using the density of the fresh water (e.g., 1,000 kg m^{-3}). This is used for calculating the horizontal hydraulic gradient and flow direction.

Point-Water Head - the sum of the elevation head and the pressure head calculated using the density of the water at the point sampled.

Pressure Head - head caused by the pressure (energy) of the fluid.

Velocity Head - head caused by the kinetic energy of the flowing fluid.

Total Dynamic Head - the actual height to which the water is to be pumped. It is the sum of static lift (depth to the water level in the well), static height (the elevation to which water will be pumped along the delivery pipeline), and friction loss (resistance to water flow expressed as height per length of delivery pipe).

Health-Based Screening Level (HBSL) - an estimate of concentration or concentration range in water that 1) maybe a potential concern for human health; 2) can be used as a threshold value to compared contaminant concentrations in groundwater samples; and 3) is consistent with standard methodologies.

Heat Capacity - the quantity of heat absorbed per unit quantity (mass or volume) for a temperature increase of one unit; essentially the equivalent of specific heat.

Heat Flux - the transport of heat across a surface.

Latent Flux - flux of heat from the Earth's surface to the atmosphere from evaporation of water at the surface and subsequent condensation of water vapor.

Sensible Flux - flux of heat from the Earth's surface that is transported via conduction and/or convection. Sensible heat is the product of the body's mass, its specific heat capacity, and its temperature above a reference temperature.

Heat of Fusion - the amount of heat necessary to convert ice into liquid water.

Heat of Vaporization - the amount of heat necessary to convert liquid water into water vapor.

Heavy Water - water that has a very high proportion of the deuterium isotope.

Heliophyte - a plant that thrives in full sunlight.

Helium - the element with 2 protons and 2 neutrons (^{4}He). It is an inert, stable noble gas.

Terragenic helium - helium derived from mantle or crustal sources

Tritiogenic helium - helium (^{3}He) derived from radioactive decay of tritium.

Herbicide - a chemical compound used to destroy or control plant growth.

Henry's Law - at a constant temperature, the amount of a given gas dissolved in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid.

Henry Sampler - a thin, push-point sampler for measuring water levels or sampling pore fluids.

Herbicide – a chemical designed to control or destroy noxious plants.

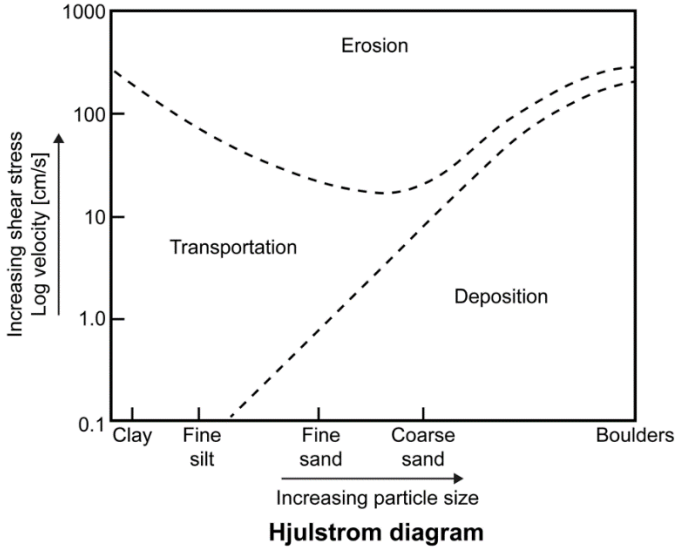
Heterogeneity - the condition in which the property of a parameter or a system varies with space; spatial distribution of properties. Same as *inhomogeneity*.

Heuristic -

1) a heuristic or heuristic technique is an approach to problem solving or self-discovery employing a practical method that is not guaranteed to be optimal, perfect, or rational, but is sufficient for reaching an immediate, short-term goal or approximation. Where finding an optimal solution is impossible or impractical, heuristic methods can be used to speed up the process of finding a satisfactory solution.
2) involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods.

High-Level (Radioactive) Waste - radioactive waste from spent fuel rods, the reprocessing of spent fuel rods from nuclear reactors, and some radioactive materials from the US Defense Department.

Hjulstrom Diagram - a plot of stream velocity versus streambed grain size with the fields of deposition (sedimentation), erosion, and transportation.



Hjulstrom diagram

Hobson's Formula - relates the height of water capillary rise (h_c) into a free-phase NAPL (Non-Aqueous Phase Liquids) as a function of pore (r_p) and pore throat (r_t) where σ is the water/NAPL interfacial tension; θ is the contact angle between the water and the NAPL and ρ_w and ρ_{NAPL} are the densities of the two fluids, as shown by the following equation.

$$h_c = \left[2\sigma \cos\theta \left(\frac{1}{r_t} - \frac{1}{r_p}\right)\right] / [g(\rho_w - \rho_{NAPL})]$$

Homogeneity - the property of a parameter or system whose values are unchanged over space.

Hooke's Law - strain (ε) is elastic and directly proportional to stress ($\varepsilon = \alpha \cdot \sigma$) or α, where α is compressibility.

Hot Spring - a thermal spring with a discharge temperature higher than that of the human body (i.e., 36 °C/98 °F).

HSPF (hydrologic simulation program-FORTRAN) – a process-based watershed model that quantifies runoff and addresses water quality impairments from point and nonpoint sources.

Human-Health Benchmark - the threshold concentration above which the concentration of a contaminant in drinking water could have adverse effects on human health.

Humidity - moisture; dampness.

Absolute Humidity -

1) density of water vapor in moist air or
2) mass of water per unit volume of air (gm/m^3).

Relative humidity - the percentage of moisture in air relative to the amount it can hold at saturation at a given pressure and temperature.

Hvorslev Method - a method for evaluating slug-test data (Hvorslev, 1951) in unconfined systems.

Hydraulic Conductivity (*K*) -

1) the volume of fluid that flows through a unit area of porous medium for a unit hydraulic gradient normal to that area; or
2) the coefficient of proportionality between fluid flux and the hydraulic gradient in Darcy's Law; or
3) in a general sense, a measure of a porous medium to transmit water.

The term *permeability coefficient* is used in some old literature.

Effective Hydraulic Conductivity - the hydraulic conductivity of a given fluid in systems that contain more than one fluid (e.g., oil-water and air-water systems).

Hydraulic Diffusivity - the ratio of hydraulic conductivity (K) to specific storage (Ss) or the ration of transmissivity (T) to storativity (S).

Hydraulic Fracture - a fracture created by the nature or human-induced fluid pressure.

Hydraulic Gradient (i or ∇h) - the change in hydraulic head with direction.

Hydraulic Head (h) -

1) the elevation in a well in reference to a specific datum or
2) the mechanical energy per unit weight of water (L).

Gravitational Head - the component of total hydraulic head relative to the position of a given mass of water relative to an arbitrary datum. The same as *elevation head*.

Static Head - the height, above a datum, of the surface of a column of water that can be supported by the static pressure at a given point. Essentially the sum of elevation head and pressure head.

Hydraulic Potential (Φ) - fluid mechanical energy per unit mass (L^2T^{-2}). $\Phi = gh$.

Hydraulic Radius (*R*) - the quotient of cross-sectional area of a stream, conduit, or fracture and its wetted perimeter.

Hydric Soil - a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper soil layers.

Hydrocarbons - covalently bonded molecules containing only carbon and hydrogen.

Aliphatic Hydrocarbons - contain a carbon atom framework of straight or branched carbon chains including alkanes and alkenes.

Alicyclic Hydrocarbons - contain a ring of carbon atoms in their structure that may have side chains.

Aromatic Hydrocarbons (e.g., Benzene and Toluene) - contain a single planar ring of six carbons with a delocalized aromatic ring of electrons that confers stability on the molecule, thus persistence in the environment.

Polycyclic Aromatic Hydrocarbons (PAHs) - contain multiple adjacent (fused) aromatic rings.

Hydrochemical Facies - zones of differing groundwater chemistry over space. Typically, the facies reflect the major ionic constituents in groundwater. This is related to *Collins, Durov, Piper, Schoeller, Stiff, Sulin*, and *Taussig diagrams*.

Hydrocompaction - the combined volume decrease and density increase that occurs when moisture-deficient sediments compact as they are wetted.

Hydrodynamic Dispersion - the dispersion or spreading of solutes, colloids, or heat in a groundwater system that is caused by variations in the velocity and direction of flow.

Hydrogeology -

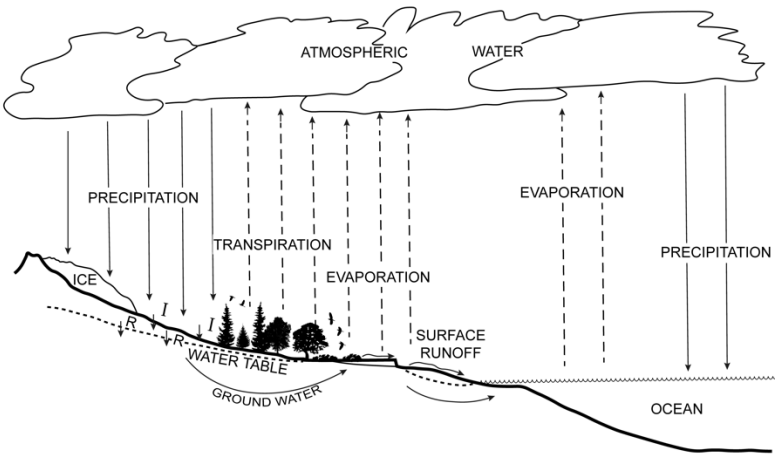
1) the study of subsurface water, including its physical and chemical properties, geologic environment, its role in geologic processes, natural movement, recovery, contamination, and utilization; or
2) the study of groundwater: How water gets into the ground (recharge), how it flows in the subsurface (through aquifers), and how groundwater interacts with the surrounding soil and rock (the geology) https:/iah.org/education/general-public/what-is-hydrogeology↗; or
3) the study of groundwater with particular emphasis given to its chemistry, flow systems, and relation to the geologic environment (Davis & DeWeist, 1966, p.1); or
4) the study of water below the Earth's surface (Pinneker, 1983, p.1).

Commonly, geohydrology, hydrogeology, and groundwater hydrology are used interchangeably, but there are subtle distinctions such as geohydrology having a stronger hydrology emphasis, hydrogeology having a stronger geology emphasis, and groundwater hydrology having a stronger engineering emphasis.

Hydrogeomorphic Index – a wetland classification system developed by the US Department of Agriculture (2008).

Hydrograph - a chart depicting either discharge or water level as a function of time.

Hydrologic Cycle - the circulation of water over, upon, and beneath the surface of the Earth (or planetary body).



Hydrologic cycle

Hydrologic Unit - a geographic area representing all or part of a surface drainage basin or a distinct hydrologic feature. In the USA these units have eight-digit identification numbers.

Hydrology -

1) broadly, the study of the waters of the Earth (or other planetary bodies); or
2) a distinct geoscience interactive on a wide range of spatial and temporal scales with the oceanic, atmospheric, and solid earth sciences, as well as with many of the biological sciences; or
3) *a legal definition* from the state of Wisconsin in the USA, (https://docs.legis.wisconsin.gov/statutes/statutes/470↗), a science that involves the study of the waters of the earth, including the study of the occurrence, circulation, distribution, chemistry or quality of water or its role as a natural agent that causes changes in the earth, and the investigation and collection of data concerning waters in the atmosphere or on the surface or in the interior of the earth, including data regarding the interaction of water with other gases, solids or fluids.

Hydrometer - an instrument that measures the density or relative of liquids.

Hydroperiod - the length of time that a wetland is covered with standing water.

Hydrophilic - having a tendency dissolve in, be wetted by, or mix with water.

Hydrosphere - a generic term for all the water in, above, and on the Earth.

Hydrostatic Equilibrium - a system in which every point is at hydrostatic pressure.

Hydrostatic Level - the level to which water will rise in a well under its full [hydrostatic] pressure head. It defines the potentiometric surface.

Hydrostatic Pressure - the pressure exerted by water at any given point in a body of water at rest.

Hydrostratigraphic Mapping - mapping of a part of a body of rock (or soil) that forms a distinct hydrologic unit with respect to groundwater flow.

Hydrostratigraphic Unit - a formation, part of a formation, or group of formations of significant lateral extent that compose a unit of reasonably similar hydrogeologic properties and responses to hydraulic stresses. Also called a hydrogeologic unit.

Hydrothermal Fluid - a mineralized solution heated by contact with hot rocks and/or cooling magma and convecting within a subsurface reservoir.

Hydrothermal System - a groundwater system that has a source (or area) of recharge, a source (or area) of discharge, and a heat source.

Hydrovolcanic – a term encompassing all volcanic activity resulting from interactions of lava, magmatic heat, and gases with meteoric or connate water at or near the surface of the Earth.

Hyetograph - the time history of rainfall depth on the ground for a specific location or specific area.

Hygrophilic - applies to terrestrial organisms adapted to moist conditions and that seek out humid microclimates.

Hygroscopic - tending to sorb water from the air.

Hygroscopic Coefficient -

1) quantitatively, the capacity of a soil for holding hygroscopic water or

2) the percentage of water in soil which, in a dry condition, has been brought into a saturated atmosphere and kept in that atmosphere at a constant temperature until it has absorbed all the atmospheric water vapor that it is capable of absorbing.

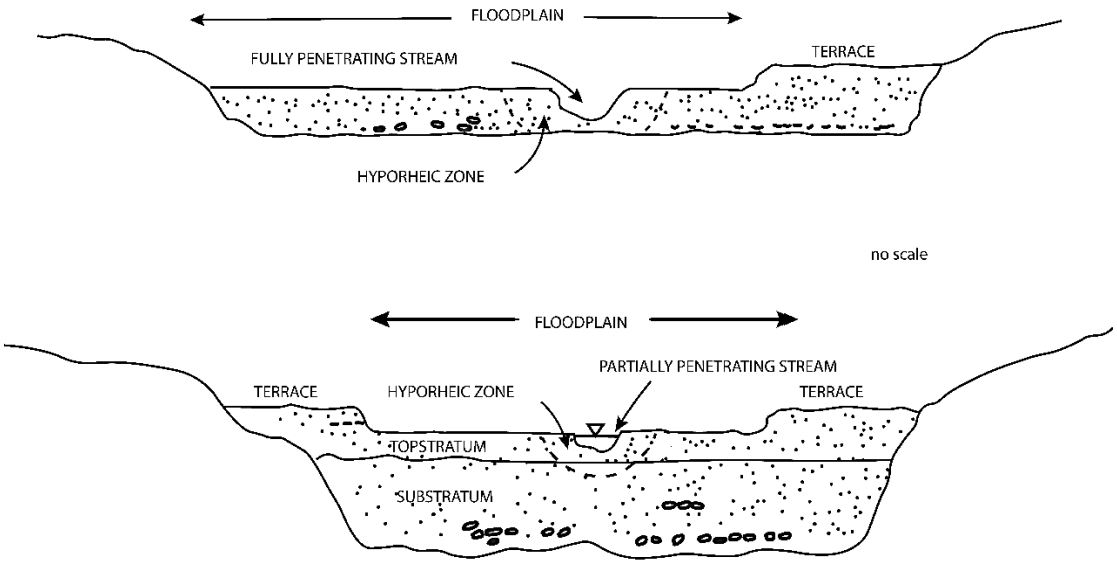
Hygroscopic Water -

1) water in the unsaturated zone that is so tightly bound to the solid particles that it cannot be removed by gravity or plant root suction, or
2) water in the soil in an extremely thin, tightly held film around soil particles.

Hypogean - that which lies beneath the surface of the Earth.

Hypolimnion - the cooler, denser bottom layer of water in lake. This is related to *epilimnion* and *thermocline*.

Hyporheic Zone - the zone in alluvial sediments where the chemistry of the pore fluids is influenced by the mixing of groundwater and surface water.



Hyporheic zones in alluvial aquifer systems

Hysteresis - the phenomena in which a process or the value of a variable in a process is dependent upon the past history of the process.

I

Ice - the solid form of water.

Ichnofabric Index - the degree of bioturbation in a sedimentary rock. The Droser-Bottjer ichnofabric index is used to quantify degree of bioturbation, grading the amount of trace fossil activity on a scale of 1–6; a value of 1 indicates that bioturbation is entirely absent, whereas the highest grade would indicate a bedding plane containing over 60% trace fossil cover.

Ichnofossil - a trace fossil, consisting of burrows, borings, urolites (representing where sediment was displaced by a urine stream), footprints, feeding marks, and root cavities. These may affect subsequent rock porosity and permeability.

Ignatovich-Souline Sequence - see *Chebotarev Sequence*.

Illuviation - introduction of salts or colloids into a soil horizon by downward percolation of water.

Imbibition - the displacement of a non-wetting fluid by a wetting fluid due to capillary forces independent of any external pressure gradient.

Immiscible - the condition where two or more liquids, or phases, do not readily dissolve in one another (e.g., oil and water).

Impermeable - Synonymous with *impervious*.

1) impervious to a fluid, or
2) a material with zero permeability.

Infiltration - the movement of water from the surface of the land into the subsurface (vadose zone).

Induced Infiltration - infiltration caused by the lowering head below surface water levels by pumping or drainage.

Infiltration Capacity - the maximum rate ($L^3T^{-1}L^{-2}$ or LT^{-1}) at which a soil at a given condition can absorb rain as it falls. Infiltration capacity is a function of the saturation and permeability of the soil.

Infiltration Rate - the rate of water entry into the soil (LT^{-1}). Infiltration rate can change with time but cannot exceed the infiltration capacity.

Influent Stream - a stream that loses water to the groundwater. Also called a *losing stream*.

Injection Well -

1) a well that is used for the injection of water for any purpose, including artificial recharge and waste disposal, or
2) a well into which water is injected for the purpose of increasing petroleum reservoir pressure and sweeping petroleum to a desired location.

The US Environmental Protection Agency defines six classes of injection wells.

Class I - used for industrial and municipal waste disposal.

Class II – oil- and gas-related injection wells classified into three categories.

- Disposal wells are used to dispose of wastewater from the oil and gas industry; includes produced water extracted with the oil and gas and flowback water that returns to the surface after hydraulic fracturing.
- Enhanced recovery wells are used for the injection of fluids into oil-bearing formations to help recover hydrocarbons.
- Hydrocarbon storage wells are used for the storage of oil and other liquid hydrocarbons.

Class III - used for solution mining.

Class IV - shallow hazardous- and/or radioactive-fluid injection well. These wells, banned by the US Environmental Protection Agency in 1984, were used to dispose of radioactive or hazardous waste into or above freshwater aquifers. A few are still used in groundwater remediation.

Class V - used to inject fluids into or above underground sources of drinking water; these are mostly either stormwater drainage wells or wells leading to septic systems.

Class VI - used for geologic sequestration of CO_2.

Injection Zone - a geological formation, group of formations, or part of a formation receiving fluids through a well.

Inorganic - composed of constituents that are not plant or animal material.

Instream Flow (Instream Use) - water for uses within the defined stream channel, principally for fish and wildlife habitat and/or recreation. Sometimes referred to as *instream water*, *non-withdrawal use*, or *in-channel use*. Other uses include navigation.

Integrated Water Resource Management (IWRM) - a process that promotes the coordinated development and management of water, land, and related resources to maximize the resultant economic and social welfare without compromising the sustainability of vital ecosystems.

Intensity (of Rainfall) - the time rate of precipitation commonly measured in inches/hour or mm/hour (LT^{-1}).

Interbasin Transfer - transfers of water from one river basin to another.

Interception - the process in which precipitation is retained by vegetation and does not reach the ground surface.

Interceptor - a sewer line that receives flow from collection sewers and conveys wastewater to the treatment facilities.

Interface - the zone or surface separating waters of different salinities or separating different fluids (e.g., oil and water or water and air).

Interfacial Tension - the force per unit area arising from the free surface energy on the surface between two liquids (e.g., water and air in the unsaturated zone). The

interfacial tension between water and a NAPL (Non-Aqueous Phase Liquid) is on the order of 10 dynes/cm (MT^{-2}).

Interflow - water that infiltrates the land surface and flows into a stream but never reaches the local water table.

Intermediate Zone - a term sometimes applied to strata that are above the depths of petroleum production and below the depths of groundwater extraction. These are typically brackish water zones with limited well data.

Intermittent Stream (or Spring) - a stream (or spring) that flows only periodically.

Internal Drainage - transmission of surface water to the subsurface through karst features (e.g., dolines, caves, karren).

Interporosity Flow Coefficient -

1) the ease with which water will flow from the rock matrix into fractures in a dual porosity (fractured) aquifer during pumping, or
2) the ratio of the permeability of the matrix to the permeability of the fractures.

Intrinsic Permeability (*k*) - permeability of a porous medium that is dependent solely upon the porosity and pore structure of the medium and not the properties of the fluid (L^2 or darcy).

Intrinsic Susceptibility - a measure of the ease with which contaminants in water enter and move through an aquifer; it is a combination of the properties of the aquifer and overlying material along with the hydrologic conditions, independent of the characteristics of the contaminant and its source.

Interstice - an open space in rock or soil that can be filled with air, water, or other fluids. Synonymous with *void* or *pore*.

Ion - an atom that has lost or gained one or more electrons and thus has an electric charge.

Ion Exchange - the exchange of ions between an insoluble solid (e.g., clay minerals or organic matter) and pore fluids. Ion exchange is used in water-softening.

Ionic Strength (*I*) -

1) a measure of the electrostatic interactions among ions in solution, or
2) half the sum of the products of molality (c_i) and the square of their valence (z_i) for all (n) the ions in a solution.

$$I = \frac{1}{2}\sum_{i=1}^{n} c_i z_i^2$$

Irrigation - application of water to land for agricultural purposes.

Irrigation Return Flow - irrigation water that is not consumed thus either recharges the underlying aquifer or flows into nearby surface water bodies.

Isobar - a line of equal pressure.

Isochrone - a line connecting locations representing where an entity has the same values at a point in time (e.g., on a map showing the time it takes a drop of water on the surface to travel to the basin outlet).

Isocon (or Isoconcentration) - a line or surface of equal concentration on a map for a point in time.

Isoelectric point - the pH at which an ion, colloid, or bacteriophage has neither positive nor negative charge.

Isohyet - a line demarcating equal amounts of rainfall/precipitation.

Isolated System - a system that allows neither energy nor mass to cross its borders so that its entropy always increases.

Isopach - a line on a map through points of equal thickness of a designated stratigraphic unit or group of stratigraphic units.

Isopleth - a line or surface of constant composition.

Isoscape - a broad-area map showing the spatial distribution of isotopes.

Isotherm - a line or surface of constant temperature. This should not be confused with *sorption isotherms* or *Curie point isotherm*.

Isotope - different forms of the same element with the same atomic number (the same number of protons) but a different number of neutrons and therefore different atomic weight.

Radioactive (Unstable) Isotopes (e.g., T, ^{14}C, ^{88}Ra, ^{235}U) - decay to daughter atoms and emit α, β, and γ radiation.

Stable Isotopes (e.g., H, ^{12}C, ^{13}C, ^{16}O, ^{18}O) - do not decay radioactively.

Isotropy - the condition in which the properties of a system or a parameter do not vary with direction.

Isovel - a line or surface of equal velocity.

J

Jeopardize - present danger to the continued existence of a threatened or endangered species as a whole, as described in the US Endangered Species Act 16 USC 1531-1544. (US Fish and Wildlife Service, 1973).

Joints – naturally-occurring fractures along which there has been little or no displacement parallel to the fracture surface.

Junior Water Rights Holder (User) - one who holds water rights that are more recent than senior rights holders. Junior users cannot use water until all more senior rights are used. This is related to *senior water rights*.

Juvenile Water - water that has never before been part of the hydrologic cycle (e.g., water from comets and from volcanic exhalations).

K

Kankar (alternative spelling: Kunkur) - a sedimentological term (derived from Hindi) applied in India and the United States to detrital or residual, often nodular, calcium carbonate formed in soils of semi-arid regions. It forms sheets across alluvial plains and can occur as discontinuous lenses of nodular kankar or as indurated layers in stratigraphic profiles that are more commonly referred to as calcrete, hardpan, or duricrust. This is related to *caliché*.

Karren - dissolution feature on a rock surface; solutional sculpturing of exposed bedrock.

Rain Pit Karren - approximately symmetrical small depressions on bedrock, generally etched by rainfall.

Rill Karren - small subvertical parallel channels dissolved on steep bedrock surfaces.

Step Karren - small steps dissolved in moderately steep bedrock.

Karst -

1) a geologic terrain or surface landscape with distinctive characteristics of relief and drainage arising primarily from dissolution of rock (or soils) by natural waters, or
2) sometimes applied loosely to any dissolution in a rock (or soil) caused by flowing groundwater.

Bare Karst - karst within much-exposed bedrock.

Carbonate Karst - karst developed in limestone or dolomitic rock.

Cone Karst/Cockpit Karst - karst dotted with big solution dolines, typical of tropical regions, characterized by a pattern of steep, convex sides and slightly concave floors. The doline rims often touch adjacent doline rims.

Eogene/Eogenetic - karst that has developed on rocks that are young and have never been buried below the zone of meteoric diagenesis.

Endorheic Karst - internally drained karst with no surface outlet streams.

Epigene/Epigenic Karst - karst that develops from acidic or chemically undersaturated water flowing in shallow unconfined flow systems.

Evaporite Karst - karst developed in evaporitic rock (e.g., gypsum, anhydrite, halite). No acid is involved in the genesis of evaporate karst.

Exhumed Karst - paleokarst that has been exposed by erosion at the Earth's surface.

Hypogene/Hypogenic Karst - karst that develops from acidic or chemically undersaturated water rising from depth.

Intrastratal Karst - karst formed where solution processes take place beneath a layer of nonkarstic rock and where there may be very little or no surface expression.

Mero Karst - imperfect karst topography developed upon thin, impure, or chalky limestones where surface drainage and dry valleys exist along with karst features.

Mesogene/Mesogenetic Karst - karst developed at depths (when the rocks are deeply buried).

Paleokarst - karst formed by processes unrelated to current geological conditions and subsequently buried by younger sediments.

Phytokarst - karst formed in tropical climates by filamentous algae boring their way into limestone.

Relict Karst - karst formed by processes unrelated to present conditions and not buried by younger sediments. This is related to *paleokarst*.

Telogene/Telogenetic Karst - karst developed on rocks after their burial and subsequent exposure by uplift and erosion.

Tower Karst - karst with steep sided residual hills (i.e., towers). There may be alluvial plains and flat-floored depressions between the towers.

Urban Karst - in cities, the network(s) of utility lines, tunnels, storm drains, and other constructed subsurface openings, that respond hydraulically like a natural karst system, with double/triple porosity systems and preferred flow paths.

Volcanogenic/Magmatic Karst – karst formed by acids (e.g., H_sSO_4, H_sS, H_2CO_3, HF, and others) released by volcanic/magmatic bodies.

Karst Basin - all the surface catchments that contribute allogenic and autogenic recharge to a karst aquifer that discharges to a specific point or area.

Karst(ic) Terrains - landscapes underlain by rocks that have undergone significant dissolution by groundwater flow and have the following characteristics:

1) closed depressions of various size and arrangement,
2) disrupted surface drainage, and/or
3) caves and underground drainage systems.

Karst Valley - a valley-size, mid-size, closed depression, otherwise meeting the definition of a sinkhole but enclosing more than one smaller sinkhole and a sinking stream.

Karst Window - a large surface opening that allows a karst aquifer to be directly exposed to land surface.

Kelly Bushing - an adapter that connects the rotary table to the kelly in petroleum drilling rigs. The kelly turns the entire drill string. Depth measurements are commonly referenced to the kelly bushing (e.g., 5,000 feet KB, meaning 5,000 ft below the kelly bushing, which is generally above the land surface elevation.

Kemmerer Sampler - a device that can sample water at a specified depth in a well or surface water body.

Kersten Number (N_{Ke}) - for porous media, a dimensionless number indicating sample thermal conductivity (λ) against the thermal conductivity of the sample when it is fully saturated (λ_{sat}) and when it is completely dry (λ_{sat}).

$$N_{Ke} = \frac{\lambda - \lambda_{dry}}{\lambda_{sat} - \lambda_{dry}}$$

Kinetic Reaction - chemical reactions that occur at rather slow rates, as opposed to reactions that occur very rapidly. Kinetic reactions are slow in relation to the typical rates of groundwater flow.

Kolk - a macroturbulent eddy that may occur during flood events and is capable of deep scour.

Koeppen Climate Classification - classifies climates based upon seasonal precipitation and temperature patterns. The five main climates are tropical, arid, temperate, continental, and polar. Also called the *Koeppen-Geiger climate classification system*.

Kolmogorov Microscales (Length, Velocity, and Time) - the smallest scales in turbulent flow at which viscosity dominates and the turbulent kinetic energy is dissipated into heat. This is related to the *Taylor microscale*.

Krenegenic - of or generated by processes related to springs.

Kriging - a geostatistical method of contouring using weighted averages of surrounding data points.

L

Lacunarity - a measure of the second-order statistics, or uniformity, of fractal objects. Objects with more or larger gaps typically have higher lacunarity.

Lacustrine - relating to processes occurring in a lake.

Lag Time - the time between the middle of the precipitation event in a watershed (or catchment) and the arrival of the flood peak at a given location.

Laguna - a Spanish term for a minor lake.

Laminar - pertaining to viscous streamline flow in which the fluid flows smoothly and in regular paths without turbulence.

Landfill - land disposal sites for solid waste.

Land (Evaporation) Pan - a device to measure evaporation from a free-water surface.

Land-Use Study - a study to assess the effects of a specific type of land-use (e.g., agriculture, forest, urban) on groundwater quality.

Langelier Index - a method to predict incrusting or corrosive tendencies of a particular well water on the well screen and pipe string.

LaPlace's Equation - the equation for steady state fluid flow in a homogeneous and isotropic aquifer.

$$\nabla^2 h = 0$$

where:

h = hydraulic head (L)

Analogous equations exist for flow of heat ($\nabla^2 T = 0$) and for chemical diffusion ($\nabla^2 C = 0$).

Latent Heat - the heat required to convert a solid into a liquid or vapor, or a liquid into a vapor, without change of temperature (compare with *sensible heat*).

Latent Heat of Fusion - the heat required to melt a unit mass (or volume) of solid. For ice, this is 80 calories per gram.

Latent Heat of Vaporization - the heat required to evaporate a unit mass (or volume) of liquid. For water, this is 540 calories per gram.

Leachate - the solution created when water percolates through a material (commonly in a manmade system such as a landfill or tailings heap) and dissolves or leaches compounds in that material such as a landfill or tailings heap.

Leaching - the removal of soluble or colloidal material from a porous medium by the flow of water through it.

Leaching Fraction - the fraction of infiltrated irrigation water that passes through the crop root zone and leaches sufficient salt from the root zone to maintain viable crop productivity.

Leaching Requirement - the quantity of irrigation water required to transport salts through the soil profile to maintain a favorable salt balance in the root zone for plant development.

Leaf Area Index (LAI) - a key variable functionally related to plant biomass production, which is defined as one-sided green leaf surface area in a vegetation canopy per unit ground surface.

Leakage -

1) a flux of fluid from or into an aquifer or reservoir, commonly referring to cross formational flow; or
2) loss of water from a lake pond, or stream to groundwater.

Leakage Factor (L) - the spatial distribution of leakage through an aquitard into a leaky aquifer.

$$L = \sqrt{\frac{Tb'}{K'}}$$

where:

T = aquifer transmissivity (L^2T^{-1})

b' = aquitard thickness (L)

K' = vertical hydraulic conductivity of the aquitard (LT^{-1})

Leakance - the vertical permeability of a hydrostratigraphic unit, aquitards in particular, divided by its thickness.

Lentic - pertaining to still waters like lakes, reservoirs, ponds, and bogs.

Levee - a natural or constructed earthen, elevated, elongate, obstruction along a stream, lake, or river.

Le Châtelier's Principle - if a dynamic equilibrium is disturbed by changing the conditions, the position of equilibrium shifts to counteract the change to reestablish an equilibrium.

Ligand - a compound or molecule in solution that can combine with the ion or molecule to form a complex.

Lignite – brownish-back coal in which the alteration of the organic material has proceeded beyond that of peat, but less than sub-bituminous coal.

Limestone - a sedimentary rock composed primarily (more than 50%) of calcite ($CaCO_3$).

Limnology - the study of lakes and other freshwater bodies on the surface.

Lineament -

1) (photo) any line on an aerial photograph that is structurally controlled (e.g., stream beds, bedding planes, joint sets, tree lines on faults), or
2) (tectonic) a straight or gently curved linear feature on the Earth's surface (frequently expressed topographically as depressions or lines of depressions).

Lineaments have been related to preferred flow paths and anisotropic hydraulic conditions.

Lineation –

1) a general term for a lineament; or
2) any linear (straight or gently curved) structure in a rock at any scale.

Lining - a protective cover over the perimeter of a conduit, reservoir, or channel to prevent seepage losses or infiltration.

Liquid Limit - see *Atterberg Limits.*

Lithology - the description of rocks on the basis of physical and chemical characteristics.

Lixiviation - extracting soluble components from a solid mixture by washing or percolation (i.e., leaching).

LNAPL - a Light (less dense than water) Non-Aqueous Phase Liquid.

Loam -

1) generally, a soil that is a mixture of clay-, silt-, and sand-sized particles; or
2) more specifically, a soil that is 7 to 27 percent clay, 28 to 58 percent silt, and < 52 percent sand.

Loess - deposits of wind-blown (aeolian) silt often associated with deglaciated regions or large river valleys.

LOESS (locally **estimated scatterplot smoothing)** - a smoothing function designed to capture general patterns in stress-response relationships and reduce noise (Cleveland and Devlin, 1988).

Log (Well Log) – a linear record of a parameter value along a well as measured by a tool lowered into a borehole including the following.

Acoustic (also called Sonic Log) - measures travel time of acoustic waves in adjacent formations.

Caliper - measures borehole diameter.

Electric - measures formation electrical potential and resistivity.

Gamma - measures naturally occurring *gamma* radiation.

Gamma-Gamma (also termed a Density Log) - has a source of gamma rays and measures gamma rays returned.

Neutron - emits neutrons and measures either returned gamma rays or returning high-velocity neutrons.

SP (Spontaneous Potential) - measures the natural or spontaneous potential difference between the borehole and the surface, without any applied current

Television - provides a video image of the well/borehole.

Velocity - measures the vertical or horizontal velocity of water in a well or borehole.

Losing Stream - a stream that is recharging the adjacent groundwater system. Same as *influent stream*.

Lost Circulation - a drilling problem that arises when the circulation of the drilling fluid is interrupted and does not return to the surface because it flows into a formation instead. This is common in karstic systems.

Lotic - pertaining to swiftly flowing waters.

Low-Level (Radioactive) Waste - radioactive waste primarily from hospitals and research laboratories.

Lugeon - an archaic European measure of transmissivity in karstic rocks, determined by pressurized injection. One Lugeon (Lu) is equal to one liter of water per minute injected into 1 meter of borehole at an injection pressure of 10 atmospheres. The term is still commonly used in the grouting industry.

Lysimeter - a device for measuring the quantity, quality, or rate of water movement in the soil.

M

Macrofracture - a relatively large fracture (> 10 m in length), often with a significant aperture.

Macropore - a larger than usual pore in a soil connected to surrounding pores, typically the result of animal burrowing or plant root growth.

Magmatic Water - water that is part of a magma or that is released from the magma during crystallization. This can be plutonic or volcanic.

Plutonic Water - water that is in or has been released from magma at greater depths, on the order of several kilometers.

Volcanic Water - water that is in or has been released from magma at shallow depths or at the Earth's surface.

Major Ions - the major (or common ions) in groundwater are:

1) Anions: HCO_3^-, SO_4^{-2}, Cl^-, and sometimes NO_3^-.
2) Cations: Ca^{+2}, Mg^{+2}, Na^+, and sometimes K^+.

This is related to *Collins*, *Durov*, *Piper*, *Schoeller*, *Stiff*, *Sulin*, and *Taussig* diagrams.

Manifest - a shipping document required by the US Environmental Protection Agency for all hazardous-waste shipments that details the waste material(s), quantity, origin, route, and destination.

Manometer – an instrument of measuring pressure action on a column of fluid.

Mantle Water - water held in the Earth's mantle, the interior layer that lies between the Earth's thin, outer layer (crust) and its dense, superheated core.

Marangoni Effect - the mass transfer along a interface between two fluids due to differences in surface tension.

Marine Water - water in the ocean (or sea) or groundwater that has recently been part of an ocean (or sea) and retains the essential chemistry of the ocean water.

Marl - soft rock, chiefly composed of commingled calcium carbonate and clay formed under marine conditions. Marl can also be described as poorly consolidated calcareous claystone and as impure argillaceous limestone.

Marsh - an area periodically inundated and treeless and commonly characterized by grasses, cattails, sedges, and similar plants that typically grow in wet ground.

Matrix -

1) rock (or consolidated media) between fractures or dissolution features with no fractures visible to the naked eye, or
2) the solid framework of a porous medium.

Maximum Contaminant Level (MCL) - the maximum permissible concentration of a substance in water that is delivered to the free-flowing outlet of the ultimate user of a public water system.

Mean ($\bar{x}$) - a measure of the central tendency of a population, distribution, or sample. There are three types of means plus various types of distance-weighted means:

1) Arithmetic mean: $\overline{x} = \sum_{i=1}^{n} x_i/n$, where n = the number of samples. The arithmetic mean is suitable for normal distributions, or to estimate equivalent permeability of a surface (normal to flow), or for series in parallel.
2) Geometric mean: $\overline{x} = (\prod_{i=1}^{n} X_i)^{1/n}$, which is used for the lognormal distribution or to estimate equivalent permeability of a three-dimensional system with random heterogeneity.
3) Harmonic mean: $\overline{x} = n/\left(\sum_{i=1}^{n} {}^{1}/_{x_i}\right)$, which is used to estimate equivalent permeability of a sequence of materials perpendicular to the direction of flow. For instance, in numerical modeling the harmonic mean is used to estimate the permeability between two nodes of different permeability.

Mean Absolute Error (MAE) - measures how close predictions or forecasts (y_{ip}) are to the eventual outcomes (y_i). Alternatively, how close the simulated predictions (y_{ip}) are to measured data (y_i). For example, this may be calculated with respect to hydraulic heads or flow rates.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|y_i - y_{ip}\right|`$$

Mean Grain Size - a measure of the central tendency or the most representative grain size. When using sieve analysis, this is $(d_{16} + d_{84})/2$. d is a grain size with the subscript indicating the percentage of soil (by weight) with grain sizes less than the value of d.

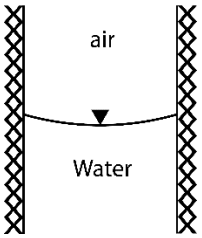
Mean Squared Error (MSE) - represents the average of the sum of the differences between the original data (y_i) and predicted values (y_{ip}) extracted from a simulation for a data set. The y values may be heads, flows, concentrations, or other simulated entity.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - y_{ip})^2$$

Median Grain Size - the middle size of a distribution. When using sieve analysis, this is d_{50} which is the size where 50 percent of the particles by weight are finer than the sieve mesh size.

Medium-Grained - sediment or clastic sedimentary rock whose particles have an average diameter of 0.5-0.62 to 2 mm (i.e., sand-size range).

Meniscus - the curved surface between two liquids or a liquid and a gas produced by surface tension.



Meteoric Water - water that is or has recently been a part of the atmospheric portion of the hydrologic cycle.

Meteotsunami - a water wave of meteorological origin generated by rapid changes in barometric pressure—such as during the passing of squalls or storm fronts—that cause the displacement of a body of water. Wave heights are generally on the order of 2 m; also called a *meteorological tsunami*.

Methemoglobinemia – a condition characterized by reduced ability of the blood to carry oxygen, commonly caused by nitrate contamination. This is also called the "blue baby syndrome."

Microburst - a localized column of sinking air (downdraft) within a thunderstorm, usually less than or equal to 2.5 miles (4.03 km) in diameter.

Microfracture - a very small fracture with a very small aperture (< 10 microns). Microfractures are commonly observed with a microscope.

Milligrams per Liter (mg/L) - the concentration of a chemical constituent as weight (milligrams) of constituent per unit volume (liter) of water; equivalent to one part per million in water of most streams and groundwater.

Milliequivalent per Liter (meq/L) - the chemical equivalence of the concentration of a solute in a solution, which is calculated by dividing its concentration (mg/L) by its equivalent weight.

Mineral Water - drinking water that contains more than 500 mg/L dissolved inorganic solids. Some mineral water may have health benefits.

Mining - in hydrogeology, this implies extraction of water from a groundwater system at a rate greater than it is being recharged.

Mining Yield - see *yield*.

Mirabilite - A white or yellow monoclinic mineral ($Na_2SO_4.10H_2O$) that commonly occurs as a residue in saline/alkali lakes, playas, salinas, and springs or as an efflorescence.

Miscible - the property where two or more liquids or phases are soluble in one another, creating a single liquid or phase (e.g., alcohol and water).

Missback Law - a modification of Darcy's Law for turbulent flow:

$$v^m = K'\nabla h$$

where:

v = fluid velocity (LT^{-1})

m = the degree of non-linearity (≈2)

K' = hydraulic conductivity for turbulent flow (LT^{-1})

∇h = hydraulic gradient (-)

Model –

1) a simplified description of a system or process that can be used as an aid in analysis or design;
2) a representation of a real system or process;
3) an assembly of concepts in the form of mathematical equations that portrays understanding of a natural phenomenon

Analytical Model -a mathematical model that provides either and exact or approximate continuous solution for groundwater flow and transport.

Conceptual Model - a clear, qualitative physical description of how a hydrogeological system behaves.

Conceptual Site Model - a schematic figure and/or description of a specific site scenario and the processes controlling contaminant transport and fate, commonly used as a framework to manage environmental risks.

Deterministic Model - a model that presumes that a system or process operates such that the occurrence of a given set of events leads to a uniquely-definable outcomes

Geotechnical Model - a ground model with predicted performance based on design parameters.

Ground Model - a geologic model with engineering parameters.

Groundwater Model - a simplified conceptual or mathematical image of a groundwater system. The mathematical models can be analytical or numerical.

Solute Transport Model - a mathematical model that predicts the movement of solutes (commonly contaminants) in the subsurface.

Modeled Available Groundwater (MAG) - in the state of Texas, USA, the volume of water that can be withdrawn from an aquifer or GCD (Groundwater Conservation District) and meet the DFC (desired future condition).

Model Calibration - adjusting values of model input parameters to match field conditions within prespecified acceptable criteria.

Model Validation - checking the accuracy of the model's representation of a system by using it to simulate measured conditions that were not used to calibrate the model.

Model Verification - the process of confirming that the model is correctly implemented with respect to the conceptual model (i.e., the model matches specifications and assumptions deemed acceptable for the given purpose of application). In a finite-element or finite-difference numerical model, this can be done by comparing model results with analytical solutions.

MODFLOW - a modular, finite-difference, numerical model for groundwater flow that was developed by the US Geological Survey.

Moffette - a vent from which CO_2 and some N and O_2 gases issue in the final stages of volcanic activity.

Mogote - an isolated, steep-sided, commonly asymmetrical hill or ridge in a carbonate landscape.

Moiety - a part or portion of a molecule, generally complex, that is responsible for characteristic chemical reactions of the molecule.

Moisture Content - the amount of moisture in a porous medium.

Gravimetric (w) - the weight of the water divided by the weight of the solids in a porous medium.

Volumetric (θ) - the volume of water divided by the total volume of the porous medium so that $\theta \leq \Phi$, where Φ is porosity.

Molality - the number of moles (gram molecular weight) of solute per 1,000 g of solvent in a solution.

Molarity - the number of moles (gram molecular weight) of a solute in one liter of solution.

Mole Fraction - the number of molecules of a substance compared to the total number of molecules in the system.

Monitor(ing) Well - a well that is used to determine and/or temporally track water levels or water quality as opposed to a well that is used primarily to either produce water or dispose of fluid.

Moonmilk – cheese-like amorphous masses of carbonate minerals and micro-organisms sometimes found on cave walls or ceilings, usually near the cave entrance.

Moraine - a term for deposits of unstratified glacial drift (*till*).

Ground Moraine - a till plain.

End Moraine - a ridge of till accumulated at the terminus of a glacier.

Moran's I Test - a correlation coefficient, ranging from -1 to 1, that measures the overall spatial autocorrelation of a data set.

1) -1 indicates a perfect clustering of dissimilar values (you can also think of this as *perfect dispersion*).

2) 0 is no autocorrelation (*perfect randomness*).
3) +1 indicates a perfect clustering of similar values (i.e., the opposite of dispersion).

Mudstone - a sedimentary rock formed by induration of silt and clay in approximately equal proportions.

Multi-Objective Optimization - a system of equations that can be used to find an optimal solution that weights the target entities and maintains them within defined constraints.

Municipal Use - use of water pumped for any purpose by a town, city, or utility district.

Mutagen - a substance that changes the genetic information (usually DNA) of an organism and thus increases the frequency of mutations (e.g., birth defects) above the natural background level.

N

NAPL - Non-Aqueous Phase Liquid, such as petroleum.

LNAPL - Light Non-Aqueous Phase Liquid, like gasoline. This fluid floats on water.

DNAPL - Dense Non-Aqueous Phase Liquid, like TCE (trichloroethene). This fluid sinks in water.

Nash-Sutcliffe Efficiency (NSE) Index (or Coefficient) - an index that assesses the predictive power of hydrological models.

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q_o^t}\right)^2}$$

where:

Q_o^t = mean of observed discharge (or chemical concentration, or other predicted entity)

Q_m^t = modeled discharge

Q_o^t = the observed discharge at time t

T = the total number of time periods

Natural Attenuation - the reduction of constituent concentrations by natural (biological, chemical, and/or physical) processes.

Natural Disturbances (of a Groundwater-Dependent Ecosystem) - these include (but are not limited to) floods, droughts, and biological pathogens, including diseases and parasites.

Natural Resource -

1) a natural source of wealth or revenue; often used in the plural, or
2) an accessible supply that can be withdrawn when necessary.

Naturalized Stream Flow -

1) stream flow that would have occurred if people had not entered the basin (or watershed), or
2) gauged stream flow adjusted to remove the effects of water management activities (e.g., diversions, reservoir operations, discharge of wastewater,

groundwater pumpage, and discharge of pumped water such as mine dewatering).

Navier-Stokes Equation - the fundamental equation of motion for a viscous fluid of constant density (ρ) and viscosity (μ).

$$\rho\left(\frac{\partial v}{\partial t}+v_x\frac{\partial v}{\partial x}+v_y\frac{\partial v}{\partial y}+v_z\frac{\partial v}{\partial z}\right)=-\nabla p+\mu\nabla^2 v+\rho\underline{g}$$

where:

ρ = fluid density (ML^{-3})

$\underline{g}$ = gravitational acceleration (LT^{-2})

$v\ (x, y, z, t)$ = velocity (LT^{-1})

p = pressure ($ML^{-1}T^{-2}$)

Neotectonic Fractures/Joints - fractures or joints that have formed in response to the present stress field. Neotectonic fractures are characterized as single sets of parallel fractures.

Neutron Probe - a device that measures hydrogen concentration to estimate porosity in the saturated zone and to estimate soil moisture content in the unsaturated zone.

NIMBY – an acronym for Not In My Back Yard, which means 'conduct some operation (e.g., sanitary landfill, reservoir, or other facility) somewhere that will not inconvenience me.'

NIMTO – an acronym for Not In My Term in Office, which means "this is a politically risky decision that the politician wishes to postpone until they decide not to run for office again."

Nitrate - an ion consisting of one nitrogen atom and three oxygen atoms (NO_3). Nitrate is a plant nutrient and is mobile in soils.

Nitrification - the formation of nitrates by the oxidation of ammonium salts to nitrites followed by oxidation of nitrites to nitrates.

Nitrite - a compound containing the radical NO_2^-.

Noncondensable Gases (NCG) - gases such as carbon dioxide, hydrogen sulfide, methane, among others, in very small concentrations that are constituents of geofluids, either dissolved in liquids or as gaseous components of steam.

Nonconsumptive Use - water use that does not substantially deplete the water supply such as recreational uses (e.g., boating, fishing, swimming), hydropower generation, and maintenance of fish and wildlife habitat.

Non-Darcian - the term implying that flow in a porous medium does not follow Darcy's law (i.e., the discharge is not linearly proportional to the hydraulic gradient).

Nonpoint Source - a source of pollution that cannot be traced to a definable single place but rather is sourced from a number of points that are widespread (e.g., pesticides applied to an agricultural field, salt applied to icy roads, sewage effluent form a developed area where the homes use septic systems).

Normalized Difference Water or Wetness Index (NDWI) - an index based on satellite image analysis that identifies water bodies, areas of high humidity, and/or areas of high soil saturation.

Normalized Difference Vegetation Index (NDVI) - a remote sensing index for the study of vegetation cover. NDVI is used to identify terrestrial ecosystems and wetlands that depend on groundwater.

Nutrient - any element or compound, including pollutants, that fuels or feeds organic-rich aquatic systems.

O

Occam's Razor - the simplest explanation is preferable to more complicated explanations.

Octanol-Water Partitioning Coefficient (K_{OW}) - the ratio of a chemical's concentration in the nonpolar octanol phase and the polar water phase.

Ohm's Law - the electrical flux (current flow) is proportional to the voltage and inversely proportional to the resistance as expressed in the following equation.

$$I = \frac{V}{R}$$

where:

I = current flow, typically in amperes (I)

R = resistance, typically in ohms ($ML^2T^{-3}I^{-2}$)

V = represents ∇V, the voltage drop over the system typically in volts ($ML^2T^{-3}I^{-1}$)

Oligotrophic - water bodies with a low supply of plant nutrients. This is related to *eutrophic*.

Olistostrome - a sedimentary deposit composed of a chaotic mass of heterogeneous materials such as blocks and mud known as olistoliths that accumulate as a semifluid body by submarine gravity sliding or slumping of the unconsolidated sediments. It is a mappable stratigraphic unit that lacks true bedding but is intercalated among normal bedding sequences.

Olsthoorn's Infiltration Theory - the relation between pressure increase and clogging of a well caused by straining (i.e., sieving) and physical-chemical filtration.

$$\Delta h_v = \left(\frac{1}{\rho_w g}\right)\left(\frac{c\mu_d}{k_c}\right)v^2 t$$

where:

Δh_v = increment of pressure head caused by clogging (L)

ρ_w = density of water (ML^{-3})

g = gravitational acceleration (LT^{-2})

c = concentration of suspended matter in the infiltrating water (ML^{-3})

μ_d = dynamic viscosity ($ML^{-1}T^{-1}$)

k_c = intrinsic permeability of the filter cake (L^2)

v = infiltration rate (LT^{-1})

t = time (T)

Ombrothermic Index (OI) - characterizes bioclimatology by evaluating the availability of soil water for plants during the driest months of the year. OI is the quotient of positive annual precipitation (accumulated monthly precipitation when the average monthly average temperature is greater than 0 °C) and the positive annual temperature (average monthly temperature values greater than 0 °C).

One Percent (1 percent) Rule of Thumb -

1) a generality that sampled concentrations of DNAPL (Dense Non-Aqueous Phase Liquid) in groundwater in excess of 1 percent of the effective solubility indicate that DNAPL may be present as free product in the vicinity of the sampling point, or
2) the assumed value of organic carbon content in a sediment in the absence of data.

Open System - a system that allows both energy and mass to cross (or flow across) its borders (e.g., an aquifer).

Optimal Yield - see *yield*.

Organic Carbon – carbon that originates in plants or animals and is bound in an organic compound.

Organic Matter - matter resulting from the decay of a plant or an animal and containing organic carbon compounds.

Osmosis -

1) the flow of water in response to a chemical gradient, or
2) the transport of a solvent usually water through a semipermeable membrane from the fresher side toward to the more saline side.

Ostrom Principles - design principles for stable local management of groundwater and other common pool resources.

Outcrop - where a formation is present/exposed at the Earth's surface.

Outlier - a surface expression of a geologic unit that is not connected to the main part of the geologic unit outcrop.

Outwash - fluvial deposits (mostly sand and gravel) created by sediments settling out of meltwater streams from glaciers.

Overdraft (or Over-Pumping) - pumping of groundwater at rates faster than the rate that groundwater is recharged.

Overflow - in karstic systems, an overflow conduit or system is a shallower flow path that generally flows at times of high-water tables (in contrast with an underflow conduit). It is typically an open system with respect to the atmosphere.

Over-Exploitation - overdraft of groundwater that creates undesirable effects.

Overland Flow - the flow of water over the land surface created by direct precipitation. Also called *Horton(ian) overland flow*.

Oxbow Lake - a small floodplain lake left when a stream meander is cutoff.

Oxic Water - water with a concentration of dissolved oxygen greater than or equal to 0.5 mg/L.

Oxidation -

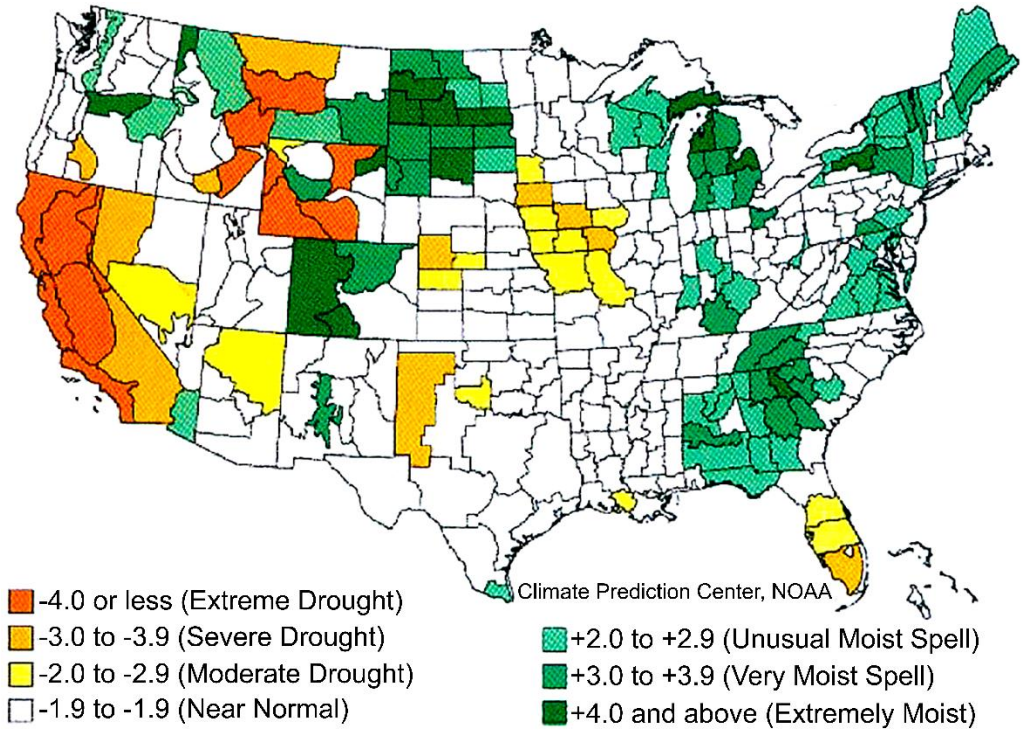
1) elements gaining electrons, or
2) all chemical reactions in which atoms have their oxidation number (oxidation state) changed (e.g., the oxidation of carbon to yield carbon dioxide, CO_2), or
3) loss of electrons by a chemical species as a result of transfer to another chemical species (e.g., dissolved oxygen). The species donating electrons is *oxidized*.

P

Packer -

1) an inflatable tool on a drill string that is used to seal off lengths of a borehole, or
2) a device lowered into a well to produce a fluid-tight seal.

Palmer Drought Severity Index (PDSI) - a system that uses readily available temperature and precipitation data to estimate relative dryness of a region. The index categories are extreme drought, severe drought, moderate drought, near normal, unusually moist spell, very moist spell, and extremely moist. This is related to the *Aridity Index* and *Budyko Aridity Ratio*. (https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi↗).



PDSI for the United States, January 2014.

Parameter -

1) a defined physical quantity with a numerical value or a value within a certain range, or
2) a characteristic of a population (e.g., the mean), or
3) an algebraic symbol representative of a well-defined quantity with a numerical value.

Parshall Flume - a calibrated device based upon the principle of critical flow that is used to measure the flow of water in open conduits; also called an improved *Venturi flume*.

Particle Size - a linear dimension (usually a diameter) that characterizes the size of a particle; synonymous with *grain size*.

Partial Penetration (of a Well) - a situation where the intake portion of a well (*well screen*) is less than the full thickness of the aquifer.

Partings - fractures along bedding planes.

Partitioning Coefficient (K_d) - the partitioning of a solute between the fluid in the pores and the solid porous medium.

Passage - an elongated portion of a cave; usually a conduit for groundwater flow.

Pathogen - a disease-producing organism/microbe.

Peclet Number (N_{Pe}) - the ratio of solute transport by convection to solute transport by diffusion (or dispersion); also, the ratio of heat transport by convection to heat transport by conduction.

Pedogenic - a term for processes occurring in soil or resulting in the formation of soil.

Pelecypod - any benthic aquatic mollusk with a bivalve shell (e.g., clams, oysters).

Pellicular Water - water in films adhering to solid particles in the unsaturated zone. Pellicular water includes hygroscopic water and gravitational water.

Peltier Effect - heat flow caused by an electrical field.

Pendular Water - water that hangs from mineral particles in the unsaturated zone.

Penman Method - a method of estimating evapotranspiration.

Perched Aquifer, Perched Water Table, or Perched Zone - a body of saturated rock or soil above the regional water table, below which is an unsaturated zone. The base of the perched system is typically a low-permeability layer.

Percolation - downward flow of groundwater through the unsaturated zone that is driven by gravity.

Percolation Rate -

1) the rate at which water flows through a porous medium,
2) the rate of vertical movement of water through the vadose zone, or
3) the intake rate used for design of wastewater absorption systems.

Percolating Waters -

1) waters passing through the ground beneath the Earth's surface without a definite channel (legal term), or
2) water flowing downwards through pores, cracks, and tight fissures in the vadose zone.

Perennial Stream (or Spring) - a stream that flows continuously all year. This is related to *ephemeral* and *intermittent streams*.

Perforate - to pierce a well casing so as to provide holes for formation fluids to flow into the well or for materials to be introduced into the annular space of the well.

Permafrost - permanently frozen ground that can occur in arctic, subarctic, or alpine regions; ground (rock or soil) that remains below freezing temperatures all year.

Permafrost Table - the depth at which the maximum annual groundwater temperature never rises above zero °C; the top of the permafrost. The active layer (that freezes and thaws) lies above the permafrost table.

Permanent Hardness - water hardness due to the presence of noncarbonate hardness ions that will not be precipitated by boiling.

Permeable - able to transmit/pass water or other fluids.

Permeability - the ease with which a porous medium can transmit water or other fluids. Permeability can be defined for either laminar (darcian) or non-laminar (non-darcian) flow.

Dual Permeability - the permeability of a porous medium that has both primary and secondary permeability (e.g., fractured rocks, karst)

Crustal Permeability - the capacity for groundwater to flow upwards through the tectonically active continental crust creating pathways for geothermal fluids.

Intrinsic Permeability (k) - the permeability of the medium independent of the type of fluid present (L^2). Also called the *absolute permeability*.

Primary Permeability - permeability of the primary pore system.

Relative Permeability (k_r) -the permeability of the medium for a specific fluid relative to the intrinsic permeability ($k_r \leq k$) for a porous medium containing more than a single fluid phase (e.g., air and water; or oil, gas, and water).

Secondary Permeability - permeability of the secondary pore system.

Triple Permeability - permeability in a karstic system where there is flow in the matrix, the fractures, and conduits/caves.

Permeability Index (PI) - a ratio used in the classification of waters for their use in irrigation. PI is expressed as follows with C representing ionic concentrations in meq/L.

$$PI = \frac{C_{Na} + \sqrt{C_{HCO_3}}}{C_{Ca} + C_{Mg} + C_{Na}}\ 100$$

Permeability Scale Effect - the increase of permeability as a function of increased scale of measurement.

Permeameter - a device for measuring permeability.

Persistence Ratio ($_AP_B$) - the ratio of the number of fractures crossing both beds A and B divided by the number of fractures crossing bed A only.

$$_AP_B = (A + B)/A$$

Pesticide - a chemical or biologic compound used to control undesirable plants and animals.

PFAS (Per- and Poly-FluoroAlkyl Substances) - include perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), which are two widely used chemicals. PFAS may break down very slowly and can build up with time in people, animals, and the environment. PFAS are used in products to improve their resistance to heat, oil, stains, grease, and water. They are also used in fire fighting.

pH - a measure of the acidity or alkalinity of a solution based upon the negative logarithm of the hydrogen ion concentration. pH < 7 is acidic; pH > 7 is alkaline (basic); and pH = 7.0 is neutral. This is related to *acidity*. pH originally stood for "potential of Hydrogen."

Phenotype - the composite of an organism's observable traits or characteristics (e.g., morphology, development, behavior). This is related to *genotype*.

Phreatic -

1) of or pertaining to groundwater, or
2) the space below the water table where all the pores are filled with fluid, usually with groundwater.

Phreatic Eruption - a volcanic eruption consisting of mostly steam. These are caused by the interactions of magma with groundwater.

Phreatic Water –

1) A term originally applied to only to the water that occurs in the upper part of the saturated zone under water-table conditions (unconfined groundwater)
2) all water in the saturated zone (groundwater).

Phreatic Zone - water in the zone beneath the water table where the fluid pressure is equal to or greater than atmospheric pressure. This is related to *zone of saturation*.

Phreatomagmatic (Hydrovolcanic) Eruption - volcanic explosion that extrudes both magmatic gases and steam; it is caused by the contact of magma with groundwater or shallow surface water.

Phreatophyte - a water-loving plant that typically obtains its water directly from the water table or from an adjacent body of water (e.g., willows, salt cedars, sedges).

Phylogeography - the study of the spatial distribution of genealogical lineages within and among intraspecific populations and closely related species, especially in karstic systems.

Physiographic - having a distinctive, identifiable geologic form and history.

Phytoremediation - using plants to extract contaminants from water.

Phytotoxin - a poisonous plant constituent that is harmful to humans or other animals.

Pi Number (N_{Pi}) - the relative magnitude of vertical flow caused by buoyancy/density effects to horizontal flow by forced convection as shown by the following equation.

$$N_{PI} = \frac{K_v\left(\frac{\Delta\rho}{\rho_o}\right)}{K_h \nabla h}$$

where:

K_v and K_h = vertical and horizontal hydraulic conductivity, respectively (LT^{-1})

$\Delta\rho$ = the change in density caused by salinity and temperature relative to a reference density, ρ_o, (ML^{-3})

ρ_o = the reference density (ML^{-3})

∇h = hydraulic gradient in the horizontal direction (LL^{-1}) thus (-)

Picocurie (PC or pCi) - one trillionth (10^{-12}) of the amount of radioactivity represented by a Curie, which is the amount of radioactivity that yields $3.7x10^{10}$ radioactive disintegrations per second. One PC = 2.22 dpm (disintegrations per minute).

Piezoelectricity - flow of electricity caused by a pressure gradient.

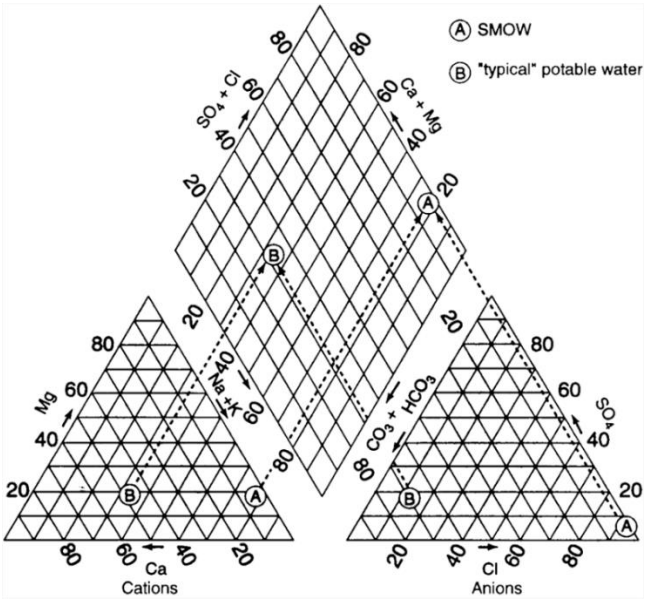
Piezometer - a pressure-measuring device. Typically, it measures fluid pressure at a given point rather than integrating pressures along the length of a well. Piezometers are commonly a vertical tube or well that is open or slotted a specific depth.

Piezometer Nest - a group of piezometers at one location with test interval at different depths.

Piezometric Surface - see *potentiometric surface*.

Pinnacle - the residual block of limestone between cutters.

Piper Diagram - a graphical means of displaying the ratios of the principal ionic constituents in water (modified from Davis & DeWeist, 1966; Freeze & Cherry, 1979).



Piper diagram. The acronym SMOW is Standard Mean Ocean Water.

Piping - erosion of unconsolidated material by flowing groundwater.

Pitzer Parameters - correction factors for estimating solubilities in concentrated (strong electrolyte) solutions.

Planar Flow - two-dimensional flow where streamlines lie in parallel planes (e.g., shallow water flowing over a land surface during heavy rainfall events).

Plastic - a plastic material deforms indefinitely with no increase in stress. This may imply that a critical or threshold stress has been obtained.

Plastic Limit - see *Atterberg Limits.*

Playa -

1) a dry (ephemeral) lakebed, common in semi-arid areas.
2) (in Mexico) a beach.

Plume - a three-dimensional body of fluid emanating from a point source or point sources with a chemistry or physical composition differing from the ambient groundwater, atmosphere, or surface water body.

Plutonic Water - see *magmatic water*.

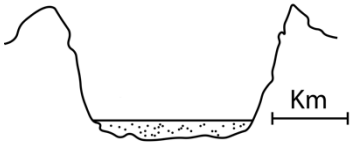
Plugging - the act or process of stopping the flow of water, oil, or gas into or out of a formation through a borehole or well that penetrates the formation.

Point Bar - one of a series of long, arcuate (i.e., curved) ridges of sand and gravel developed on the inside of a meander bend.

Point Source - a source of pollution that can be traced to or is released at a definable single place.

Poisson Process - a model for a series of discrete events where the average time between events is known, but the exact timing of events is random.

Polje - a large, flat-floored depression (from the Slavic term for field) within karst limestone, whose long axis develops in parallel with major structural trends and can be several miles (tens of kilometers) long. Superficial deposits tend to accumulate along the floor. Drainage may be either by surface watercourses (as an *open polje*) or by swallow holes (as a *closed polje*) or *ponors* which are natural opening where water enters the subsurface that are common in karst terrain. Usually, ponors cannot transmit entire flood flows, so many poljes become wet-season lakes.



Schematic of a polje.

Pollution - any aspect of water quality (physical, thermal, chemical, or biological) that interferes with an intended use.

Ponor - large karst-induced surface water inlet to the subsurface. The word derives from the Slavic term for *nora* 'pit, hole, abyss'

Pore - an opening in space to rock or soil that can be filled with air, water, or other fluids. Synonymous with *void* or *interstice*.

Pore or (Fracture) Entry Pressures - pressure that is directly proportional to the interfacial tension and wettability of the fluids, and inversely proportional to the fracture aperture.

Poroelasticity - the interaction between fluid flow and solids in a deforming porous medium.

Poroelastic Medium - a porous medium in which the deformation of the medium influences the flow of the fluid and vice versa.

Porosity (Φ or n) - the volume of the voids/pores divided by the total volume of the medium (-).

Diffusion Porosity - pores through which mass can be transferred only by diffusion; sometimes called *dead pore space*.

Dual Porosity - the porosity of a porous medium that has both primary and secondary porosity (e.g., fractured rocks, karst).

Effective Porosity (Φ_{eff}) - the interconnected porosity that contributes to groundwater flow. Often used synonymously with *specific yield*, although the two terms are not strictly synonymous.

Fracture Porosity - the porosity of the fractures.

Intergranular Porosity - the porosity between the grains of a sediment or sedimentary rock.

Matrix Porosity - the porosity, excluding fractures and dissolution features.

Primary Porosity - intergranular porosity formed during the deposition of the sediment or from vesicles in igneous rocks.

Secondary Porosity - porosity formed after the rock is lithified by either dissolution or fracturing.

Porous - having porosity greater than zero.

Porous Medium - a substance (e.g., rock or soil) that comprises both solids and voids or pores.

Potable - drinkable. For example, potable water can be safely consumed and used for cooking purposes.

Potential (Φ) - the potential energy per unit mass of fluid (with regard to a specific datum or arbitrary state).

Chemical Potential - the chemical energy per unit mass of fluid

Hydraulic Potential (Φ) - mechanical energy per unit mass of fluid that is equal to head times gravitational acceleration (L^2T^{-2}).

Matric Potential (ψ) - the total negative pressure potential.

Streaming Potential - produced when an electrolyte solution is forced to flow through a stationary capillary or a porous plug, an electrical potential difference will be produced between the two ends of capillary or porous plug. The solution carries ions with charge opposite to the surface, giving rise to a streaming current.

Zeta Potential - the potential difference existing between the surface of a solid particle immersed in a conducting liquid (e.g., water) and the bulk of the liquid.

Potentiometric Surface - a surface of equal hydraulic head or potential, typically depicted by a map of equipotentials such as a map of water-table elevations.

Practical Salinity Units (psu) - used in the oceanographic community with salinity (S) in parts per thousand. Thus, S = 2 psu = 2,000 ppm (e.g., S_{SMOW} = 34.5 psu).

Precipitation -

1) water condensing from the atmosphere and falling in drops or particles (e.g., rain, snow, hail, sleet) to the land surface, or
2) formation of a solid from dissolved or suspended matter.

Bulk Precipitation - denotes the geochemically active mixture of rainfall (or snowfall) and dry [dust] fallout.

Mesoscale Precipitation - precipitation involving heavy rainfall events and flash flooding.

Precision - a measure of the mutual agreement (or lack thereof) of individual measurements of the same property made under prescribed similar conditions; often expressed as *standard deviation* or *relative percent difference*.

Predevelopment - the time prior to substantial groundwater development by humans or substantial effects or human land uses (e.g., agriculture, deforestation, urban, etc.)

Predictability - the extent to which a prediction system can forecast the behavior of a hydrogeological or other Earth system that may be inherently chaotic.

Pressure (p) - force per unit area typically in pascals ($MLT^{-2}L^{-2}$ or $ML^{-1}T^{-2}$).

Abnormal Pressure - any departure from hydrostatic pressure. This includes overpressures and underpressures.

Aquathermal (or Thermal) Pressure - pressure produced by the thermal expansion of fluids in a medium that is less thermally expansive than the fluid in its pores.

Critical Pressure - the pressure at which consolidation of a sediment transitions from primary to secondary consolidation.

Differential Pressure - the total (or confining) pressure less the fluid pressure; essentially equivalent to *effective stress*.

Excess Pressure or Overpressure (u) - fluid pressures above the hydrostatic pressure (p_s). Also called *geopressure, abnormal pressure*, or *excess pore-fluid pressure*.

Hydrostatic Pressure (p_s) -

1) the pressure equal to that which is (or would be) induced by the weight of the overlying column of water as expressed by the following equation.

$$p_s = p_w g h$$

where:

h = height of water above the point in question (L)

ρ_w = density of water (ML^{-3})

g = gravitational acceleration (LT^{-2}),

2) hydrostatic can also refer to a pressure or stress that is exerted equally in all directions. This is sometimes-called *neutral stress*.

Lithostatic Pressure (σ) - the pressure equal to that which is (or would be) induced by the weight of the overlying column of materials of a given bulk density (ϱ_b) as shown in the following equation.

$$\sigma = \rho_b g h$$

where:

ρ_b = bulk density of the column of overlying material (ML^{-3})

g = acceleration of gravity (LT^{-2})

h = the height of the materials (rock and water) above the point in question (L)

Preconsolidation Pressure - the maximum effective vertical overburden stress that a soil or rock sample has sustained in the past.

Pressure Seal - a zone or layer of rocks capable of preventing the flow of oil, gas, or water. Seals are assumed to prevent essentially all pore-fluid flow over substantial intervals of geologic time.

Pressure Transducer - a submersible device that records water pressure and thus indicates the height of the potentiometric surface.

Primary Migration - movement of hydrocarbons from the source bed (commonly a shale) to the petroleum reservoir.

Primary Treatment - removal of floating, suspended, and settleable solids from untreated sewage.

Prior-Appropriation Doctrine – in the USA legal system, the water law concept in which the first entity (person or corporation) that withdraws and uses water from a given source holds the senior right. This has been applied to both surface water and groundwater.

Priority Date - in the USA legal system, date of establishment of a water right.

Probable Effect Level - the level of a contaminant above which negative biologic effects will probably occur. This is related to *threshold effect level*.

Proppant – small-sized particles that are mixed with hydrofracking fluids to hold fractures open after a hydraulic fracturing treatment.

Pseudokarst - a terrain with karst-like features not created by dissolution but rather by removal of clastic materials.

Public Water Supply Well - a well providing groundwater to a public water supply.

Pump and Treat - groundwater remediation using extraction (pumping) wells and surface treatment.

Pump Test or Pumping Test - one of a series of techniques to evaluate the hydraulic properties of an aquifer by observing how water levels change with space and time when water is pumped from the aquifer.

Pumpage - the quantity of water pumped in a given interval of time.

Purging - removing stagnant water from a well. This is generally conducted prior to sampling wells for chemical analysis.

Purify - remove all contaminants from a substance.

Q

Qanat (alternative spelling: Ganat) - long sloping tunnels/infiltration galleries designed to collect and transport groundwater in North Africa and the Middle East.

Quick Condition - the condition in unconsolidated media or soil where the pore-fluid pressure decreases particle-to-particle friction and reduces the load-bearing capacity.

R

Radical - a stable group of atoms that are part of a number of compounds, such as nitrite (NO_2^-), sulfate (SO_4^{-2}), and methyl (CH_3^-).

Radioactive Decay - the process by which the nucleus of an unstable atom loses energy by emitting radiation, including alpha particles, beta particles, gamma rays, and conversion electrons. The decay is measured in picocuries per liter. A material that spontaneously emits such radiation is considered radioactive.

Radiogenic Heat Production - the production of heat in a rock or sediment created by radioactive decay.

Radiolysis - decomposition induced by high-energy radiation; the radiation-induced breakdown or dissociation of materials, primarily cellulose, to generate hydrogen gas (H_2) and/or carbon compounds.

Radionuclide - an atom with an unstable nucleus.

Radius of Influence - radial distance to points where hydraulic head is no longer noticeably affected by a pumping well.

Raster - raster (or *bitmap*) images are described by an array or map of bits within a rectangular grid of pixels or dots.

Rate of Penetration (ROP) - the speed at which a drill bit proceeds through the rock being drilled.

Rating Curve - a curve that relates the discharge of a stream to the gage/gauge height.

Raoult's Law - estimates the effective solubility, C_i, typically in mg/L (ML^{-3}) as a function of the mole fraction (m_i) and the single component (e.g., gleaned from a handbook) solubility, S_i, of the i^{th} component in a mixture.

$$C_i = m_i S_i$$

This assumes ideal partitioning behavior and is commonly used to estimate the maximum concentration in groundwater immediately adjacent to a NAPL (Non-Aqueous Phase Liquid) source.

Ravinement - a planar surface carved by wave-based erosion. These surfaces tend to be low in permeability.

Rayleigh Number (N_{Ra}) - is the product of the Grashof number (Gr), which describes the relationship between buoyancy and viscosity within a fluid, and the Prandtl number (Pr), which describes the relationship between momentum diffusivity and thermal diffusivity: Ra = Gr × Pr. It is used to infer the onset of free (natural) convection that will occur when conditions result in a value of N_{Ra} above the critical N_{Ra}.

Rayleigh Darcy Number (N_{RD}) - the product of the Rayleigh (N_{Ra}) and Darcy (N_{Da}) Numbers. N_{RD} indicates the competition between buoyancy and diffusion.

RCRA (Resource Conservation and Recovery Act) - the US public law that creates a framework for the proper management of hazardous and non-hazardous solid waste.

Reaeration Coefficient (K_2) - an essential parameter to predict the dissolved-oxygen concentration in different aquatic ecosystems. For streams, K_2 can be estimated by the following equation (Parker & Gay, 1987).

$$K_2 = 252.2\, D^{0.1761}\, V^{0.355}\, S^{0.438}$$

where:

D = mean water depth (L)

V = mean streamflow velocity (LT^{-1})

S = slope of the water surface (-)

Recession - the decline of a system's output in the absence of inputs.

Recharge -

1) the process by which water enters the aquifer, the groundwater system or, more precisely, the phreatic zone.

2) the downward flow of water reaching the water table [*aquifers can also be recharged by cross-formational flow, interbasin flow, and artificial recharge.]*

Artificial Recharge -

1) replenishment of an aquifer by human activities;

2) recharge through human activities that occurs at a rate greater than naturally-occurring recharge.

Diffuse (Non-Point Source) Recharge - recharge over a broad area (e.g., precipitation, irrigation return flow from large fields).

Point Source Recharge - recharge from a small closely defined area (e.g., recharge through a sinkhole or injection wells).

Rejected Recharge - potential recharge that does not occur because the aquifer cannot accept recharge above a certain maximum rate. This becomes runoff or evapotranspires.

Recharge Basin - a basin or pit designed to allow water to infiltrate into the subsurface at rates greater than would occur naturally.

Recharge Boundary - an aquifer boundary (e.g., streams, lakes) that contribute water to the aquifer.

Recharge Zone - the area of an aquifer or aquifer system where water enters the subsurface and, eventually, the phreatic zone.

Recovery Method Test - see *Cooper-Jacob equation*.

Recurrence Interval (also called return period) -

1) the average amount of time between events of a given magnitude, or
2) estimated average time interval over which a flood of greater than a given magnitude would be expected to occur.

Redox Potential - the oxidation state of a solution.

Reduction (Reaction) - elements losing electrons; a reaction involving transfer of electrons from a more-reduced to a less-reduced (i.e., more-oxidized) substance. The species accepting electrons is said to be *reduced*.

Reduction/Oxidation (Redox) - chemical reactions involving the transfer of electrons from one chemical species to another, resulting in a change in the valence state of the species.

Reef Flat Plate - shallow (1 to 1.5 m) depth, thin (< 1 m), laterally continuous low permeability limestone layer found in tropical reefs.

Refraction - the bending of flow lines they impinge upon a contact between materials of differing hydraulic conductivity at an angle other than ninety degrees to the contact.

Refugia - a geographic region that provides a haven for flora and fauna when conditions are unfavorable over much of its distribution.

Regionalization - the process of statistically transferring information about distributions of (random) variables from locations of data collection to locations lacking data.

Regionalized Variable - a variable whose properties are intermediate between a completely deterministic and a completely random variable. There is both a random and a spatially dependent component to the values of the variable.

Regolith - the loose, unconsolidated materials that overlie bedrock.

Relief -

1) the unevenness of the Earth's surface, or
2) the vertical distance in elevation between hilltops and valley bottoms in a given area.

Remediation -

1) the process by which contaminated groundwater systems are cleansed of their pollutants, and in which the pollutants are managed to avoid their deleterious release to the biosphere; or
2) removal of contaminants from the environment.

Representative Elementary (Elemental) Volume (REV) - a volume of porous medium that is large enough for a single value to represent its properties (e.g., porosity or permeability) and in which flow can be described by a continuous function.

Reservoir -

1) an impoundment of surface water behind a dam or constructed depression, or
2) a porous and permeable subsurface formation or part of a formation containing a natural, individual, and separate accumulation of hydrocarbons (oil or gas).

Residence Time - the average amount of time that a solute, particle, organism, or other entity spends within a given system.

Residual NAPL - disconnected blobs and ganglia of NAPL (Non-Aqueous Phase Liquid) trapped by capillary forces in pores and fractures.

Residual Saturation - ratio of the volume of residual non-wetting fluid present to the volume of pore space. When a material is at residual saturation, water cannot drain by gravity from the medium.

Residuum - unconsolidated material that has developed by weathering of the underlying geological materials and which has not been transported by mass wasting, ice, water, or wind.

Resilience - ability of a natural system to mitigate or adapt to potential hazards as well as respond to and recover from the effects of an event (or hazard).

Retardation -

1) the process by which a solute is transported at a slower rate than the average linear velocity of groundwater because of partitioning onto the solid phase of the porous medium, or
2) a parameter that describes the ratio of the net apparent velocity of a particular chemical species to the velocity of a non-reactive species.

Retardation is proportional to the slope of a sorption isotherm.

Retardation Equation (or Retardation Factor) - the equation that expresses the velocity of a dissolved or suspended species (v_c) relative to the average linear velocity (v) of the groundwater.

$$v_c = \frac{v}{R_f} = \frac{v}{1 + (1-\phi)\, K_d\, \frac{\rho_s}{\phi}}$$

where:

K_d = the partitioning coefficient (L^3M^{-1})

ϕ = porosity (-)

ρ_s = bulk density of the solids (ML^{-3})

R_f = the retardation factor as defined in the next entry (-)

Retardation Factor (or Coefficient; (R_f) - a dimensionless number expressing the relative velocity of a chemical in groundwater (v_c) to that of water (v).

$$R_f = \frac{v}{v_c}$$

Return Flow - that water which is pumped from a stream, an aquifer, or a basin that is not consumptively used and returns to the stream, aquifer, or basin.

Reverse Osmosis - the flow of fluid through a membrane from the high-salinity to the low-salinity side of the membrane typically caused by exerting very high fluid pressures on the high-salinity side so that particulate matter and large diameter ions are excluded. Reverse osmosis is a common method for desalination.

Reynolds Number (N_{Re}) - the ratio of inertial forces to viscous forces. At sufficiently high Reynolds Numbers flow transitions from laminar to turbulent.

$$N_{Re} = \frac{\rho v L}{\mu}$$

where:

ρ = fluid density (ML^{-3})

μ = dynamic viscosity ($ML^{-1}T^{-1}$)

v = velocity (LT^{-1})

L = a characteristic length for a given system (L)

Rheopectic - a fluid that shows a limited increase in viscosity with time under suddenly applied (constant) shear stress.

Riffle -

1) a part of a stream with shallow rapids, or
2) the straighter section of a stream between meander bends.

Riparian - on or pertaining to the banks of a river, pond, or lake.

Riparian Doctrine - the legal system whereby the landowners adjacent to a stream have a right to use the water. This is commonly extended to groundwaters on the landowners' property.

Riprap - large rocks piled along shorelines or stream banks to reduce erosion or stabilize the bank or shore.

Risk - the probability or level of *certainty* (if there is no sample population) that a set of conditions represent a hazard. Examples include risk of landslides, floods, or groundwater contamination.

Risk-Based Corrective Action - the evaluation of the human and environmental risk of a contaminated site to determine an appropriate course of action.

River Corridor - the main river channel with connections to the hyporheic and riparian zones, including the floodplain and underlying and adjacent alluvium.

Rivulet -

1) a thin ribbon of flowing water, or
2) a small stream.

Rock Moisture - water in the unsaturated bedrock and beneath the saprolite, if present.

Rock Typing - identifying different classes of rocks by their pore-length scale, permeability, and porosity.

Roily - full of sediment; muddy or cloudy; turbulent or agitated.

Room - an exceptionally wide portion of a cave.

Root Mean Square Error (RMSE) - the square root of the sum of arithmetic mean error squared.

$$RMSE = \left[\sum_{i=1}^{n}(x_i - \bar{x})^2\right]^{1/2}$$

Root Zone - the depth in a soil to where plant roots readily penetrate and where root activity primarily occurs.

Rossby Number - the ratio of inertial to Coriolis forces for a given flow of a rotating fluid. The Rossby Number is most commonly used in oceanic and atmospheric studies.

Rosgen Classification System - a widely used method for classifying streams and rivers based on common patterns of channel morphology (Rosgen, 1996).

R-Squared (R^2) Coefficient of Determination) - the measure of how well the measured values (y_i) fit compared to the predicted values (y_{ip}). The values of R^2 range from 0 to 1 and are interpreted as percentages. The higher the value, the better the model.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_i - y_{ip}\right)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

where:

n = number of samples

$\bar{y}$ = the mean value of y_i

R-Squared Adjusted (R^2_{adj}) - a modified version of R-squared that is adjusted for the number (k) of independent variables in the model. R^2_{adj} will always be less than R^2. Inclusion of more variables makes it easier to get a good match between the measured and predicted values and this measure attempts to adjust for that.

$$R^2_{adj} = 1 - \left[\frac{(1 - R^2)(n - 1)}{n - k - 1}\right]$$

Rule of (Free) Capture – the rule of capture is the governing principle of groundwater law in Texas, USA. The rule of capture provides that because a landowner owns the water beneath his property, the landowner has the right to pump as much water as he wishes even if it adversely affects his neighbor.

Runoff -

1) water from precipitation, snowmelt, or irrigation running over the surface of the Earth; or
2) surface water entering rivers, lakes, and/or reservoirs; or
3) a component of stream flow.

Runoff Coefficient - a dimensionless number relating the amount of runoff to the amount of precipitation received. The runoff coefficient is larger in areas with low infiltration and high runoff (e.g., paved areas and steep slopes).

S

Safe Yield - see *yield*.

Saliferous – salt-bearing (compare with *saliniferous*).

Salina -

1) a place where crystalline salt deposits are formed or found such as in playas, salt flats, salt pans, salt licks, salitrals, or
2) a saline water body with a high concentration of salts such as a playa lake or salt pond, or
3) a salt marsh.

Saline -

1) the condition of containing dissolved or soluble salts,
2) anglicized form of salina.

This is related to *saline water*.

Saline Water -

1) water with from 10,000 ppm (parts per million) to less than 100,000 ppm total dissolved solids (TDS). This is the *preferred* (and simplest) definition. This is related to the definitions of *fresh water*, *brackish water*, and *brine*.
2) Hem's classification is another saline-water classification system (Hem, 1985, p. 157) and is used in some state agency publications. Hem includes the following classes:
   a) slightly saline (brackish, TDS between 1,000 and 3,000 mg/L);
   b) moderately saline (brackish, TDS between 3,000 and 10,000 mg/L);
   c) very saline (TDS between 10,000 and 35,000 mg/L); and
   d) briny (TDS > 35,000 mg/L).

Saliniferous - said of a formation yielding salt or salt water (compare with *saliferous*).

Salinity - the amount of solute (dissolved material) in water typically in ppm, mg/L, or millimoles/L), i.e., total dissolved solids (TDS).

Salinization - degradation of the soil and subsurface by the excess accumulation of salts. Salinization can also refer to increased levels of stream salinity caused by inflows of surface water or groundwater.

Salinometer - an instrument that measures the conductivity of water.

Salitral - a swampy place where salts are encrusted during dry seasons.

Salt -

1) a general term for NaCl, or
2) a general term for any dissolved material in water (synonymous with *solutes*), or
3) a surficial evaporative deposit.

Cyclic Salt - salts carried inland by wind from a body of salt water (e.g., the ocean) and ultimately returned to the sea by rivers.

Salt Damp - in Australia, a location where shallow, saline groundwater is discharging by evapotranspiration to the land surface.

Sand - soil or rock particles with an effective grain diameter between 0.62 and 2.0 mm. Sand fractions are: coarse sand (0.62 to 2 mm); medium sand (0.2 to 0.62 mm); and fine sand (0.062 to 0.2 mm).

Sanitary Landfill - a facility that handles and stores nonhazardous waste such as household garbage.

Saprolite - a thick residual soil formed chiefly in tropical or subtropical climates. Similar to an *oxisol* or *laterite*.

Saturation - when all the pores are filled with water.

Effective Water Saturation ($\bar{S}_w$) - is the quotient of the water saturation (S_w) minus the residual water saturation (S_{wr}) and (1 minus S_{wr}).

$$\bar{S}_w = \frac{S_w - S_{wr}}{1 - S_{wr}}$$

Insular Saturation (in Dual Fluid Phase Systems) - the nonwetting fluid is at residual saturation within the large pores.

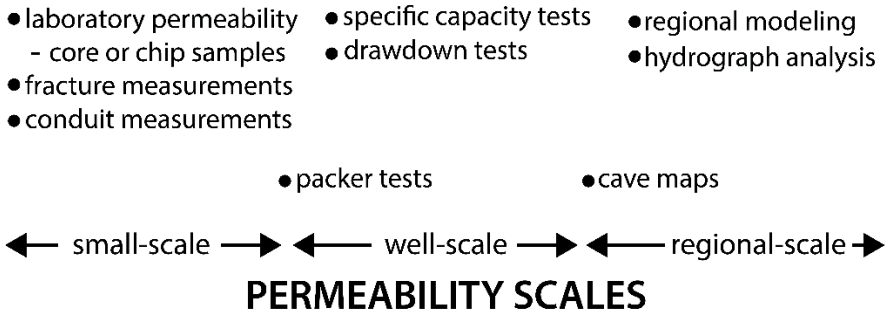
Pendular Saturation (in Dual Fluid Phase Systems) - the wetting fluid is at residual saturation across the pore throats.

Residual Water Saturation - the lowest water saturation that can be achieved by a displacement process.

Saturation (Saturated) Zone – generically, is essentially equivalent to the phreatic zone where all pore space is generally filled with liquid water. As defined, the saturation zone lies below the saturated portion of the capillary fringe and the water table.

Scalar - a number that has only magnitude (e.g., head, concentration, temperature).

Scale - the volume of measurement under consideration (Galloway & Sharp, 1998). This is related to *Kolmogorov* and *Taylor microscales* for turbulent flow.



Permeability scales and the types of measurements made on different scales. Permeability can range over 9 orders of magnitude (Halihan et al., 1999).

Gigascopic Scale - scale of depositional systems and stratigraphic sequences typically representing on the order of 10^6 years of geologic time, used for resource estimation or regional aquifer studies.

Megascopic Scale - scale of a well field that describes the external geometry of hydrostratigraphic units.

Macroscopic Scale - scale of a sedimentary facies or inter-well/inter-borehole scale.

Mesoscopic Scale - scale of lithofacies, bedding, and lamina variation occurring within genetic facies or depositional bodies such as a point bar.

Microscopic Scale - scale of individual pores and grains.

Regional Scale - measurements over a volume of 10^3 cubic kilometers or more; tests that are taken on the scale of a regional groundwater model.

Small Scale - measurements over a volume of 10^{-2} to 10 m^3 or tests that are taken in the laboratory; also called the *laboratory scale* (Dagan, 1986).

Well Scale - measurements over a volume of 10^2 to 10^3 cubic meters or tests that are taken in a well or packer tests; also called *local scale* (Dagan, 1986).

SGMA (Sustainable Groundwater Management Act) Scale - model scale suitable for defining sustainability plans for groundwater systems, based upon the USA state of California's Sustainable Groundwater Management Act (https://water.ca.gov/programs/groundwater-management/sgma-groundwater-management↗).

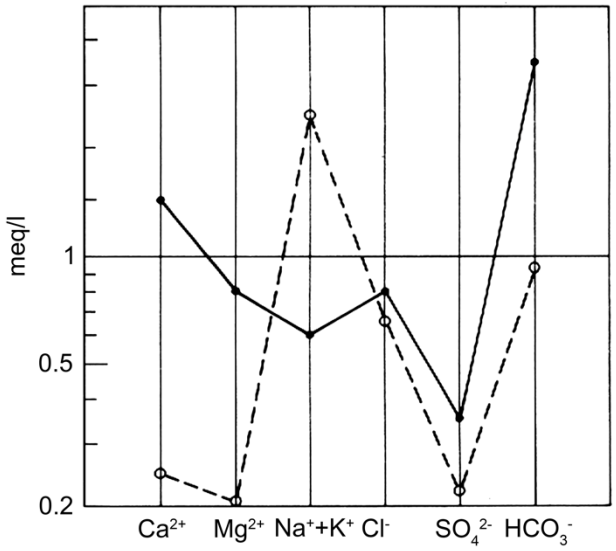
Scallop - an asymmetrical scoop-shaped solutional depression formed by flowing water. In caves, scallops can be used to estimate flow rates and directions.

Scanning Curve - paths within a general hysteresis loop.

Scarp - a line of hills or cliffs formed by faulting and/or erosion.

Scheiner-Racovitza System - classification of cave animals based upon their ecological dependence on cave habitat: trogloxenes (organisms that visit caves but do not live their entire life there), troglophiles (organisms that spend a lot of time in caves but live outside of caves without difficulty), and troglobites (organisms that spend all their life in caves).

Schoeller Diagram - a graphical means of displaying the ratios of the principal ionic constituents in water. The logs of the equivalents are connected by lines that provide an easily registered visual of the water type, as shown in the following figure.



Schoeller Diagram (Freeze and Cherry, 1979, p. 251)

Science - the branch of study in which facts are observed, classified, and analyzed; in deductive science, quantitative laws or principles are formulated and verified; deductive science involves the application of mathematical or statistical reasoning and analysis of data that has been gathered for the observed natural phenomena.

Scree - loose rock or soil covering a slope; a slope of loose rock at the base of a steep incline or cliff.

Seal - layers of low permeability in sedimentary basins that hydraulically isolate compartments of different fluid pressures.

Capillary Seal - blocks the flow of hydrocarbons (the nonwetting phase) only, but not brines (the wetting phase).

Pressure Seal - blocks the flow of both brines (water) and hydrocarbons.

Sea Level - a geodetic datum based on the average surface elevation of one or more of Earth's coastal water bodies. In North America, sea level is derived from a general

adjustment of the first-order surveying level nets of the United States and Canada, formerly called the Sea Level Datum of 1929.

Mean Sea Level (msl) -- the average height of the sea at a tide station measured from a fixed predetermined reference level.

Second Foot - a designation for stream discharge, 1 second foot is 1 cubic foot per second.

Secondary Maximum Contaminant Levels (SMCL) – the US Environmental Protection Agency (US EPA) established non-enforceable guidelines for contaminants or properties that can adversely affect the aesthetic quality of drinking water or create effects that, although undesirable, are not a health problem. Examples include unpleasant color, odor, or taste; discoloration of skin or teeth; or corrosion or staining of plumbing systems.

Secondary Migration - movement of petroleum within a reservoir or from one reservoir into another reservoir.

Secondary Treatment - Removal or reduction of suspended and dissolved solids and biological oxygen demand of sewage effluent after primary treatment.

Sediment Load - the amount of sediment carried by running water.

Seep - a site of slow or diffuse flow of groundwater to the land surface or to a body of water.

Seepage Face - a saturated face of a bank along a body of water that rises above the surface water elevation or any general area where water along a subvertical slope flows to the surface.

Seepage Force - force exerted by flowing groundwater.

$$F = \rho' \, g \, \Delta h \, A$$

where:

F = seepage force typically in pascals (MLT^{-2})

ρ' = density of water (ML^{-3})

g = gravitational acceleration (LT^{-2})
Δh = change in head for a grain or given length (L)
A = cross-sectional area of the grain (L^2)

Seepage Meter - a device that measures the rate at which water seeps into or out of the bottom and sides of a surface water body.

Selectivity Coefficient (K_s) - the equilibrium constant in ion exchange reactions.

Self-Potential - Any potential (voltage) manifested by a natural Earth process.

Semi-Arid - pertaining to climatic conditions in which the precipitation, although slight, is sufficient for growth of short sparse grass. Some semi-arid climates are referred to as a *steppe climate*.

Semivariance (γ) - a measure of the degree of spatial dependence between samples along a specific support (e.g., a support may be distance or size).

$$\gamma(h) = \frac{\sum_{i=1}^{n(h)}\left(x_i - x_j\right)^2}{2n(h)}$$

where:

$\gamma(h)$ = semivariance for lag distance h
$n(h)$ = number of data pairs within distance h of one another (–)
x_i, x_j = values of the parameter being evaluated for the data pair (dimensions of the parameter being evaluated)

Senior Water Rights - water rights that are first in time or otherwise take precedence over the rights of other water users. This is related to *junior water rights*.

Sensible Heat - heat exchanged by a body or thermodynamic system in which the exchange of heat changes the temperature of the body or system. This is related to *latent heat*.

Sequence Boundary - an unconformity or a surface representing missing time in a stratigraphic section due to erosion.

Septic System -

1) tanks and/or drain fields used to treat and dispose of domestic waste where sewer lines are not available, or
2) a well that is used to emplace sanitary waste below the surface and typically comprises a septic tank and subsurface fluid distribution system or disposal system.

Settlement - subsidence caused by the weight (load) of an artificial structure (e.g., building, embankment, road).

Sewage - human-generated wastewater that flows from houses, businesses, and industries.

Shaft -

1) a downward vertical excavation in a mine, or
2) a downward (from the Earth's surface) vertical cavity; these shafts can be formed by collapse or dissolution.

Shale - a common clastic rock composed primarily of silt and clay-sized particles that has the tendency to split into thin layers (i.e., fissility) .

Shamal - see *haboob*.

Sheet Flow - overland flow (runoff) in the form of a thin sheet of water.

Shelby Tube - a sampling device that is pushed ahead of the drill bit to collect a soil sample with minimal disturbance.

Sherwood Number (N_{Sh}) - the ratio of the rate of convection of solute transport in pore fluids to the rate of transport that would occur by steady-state diffusion.

Shrinkage Limit - see *Atterberg Limits.*

SI units – the International System of Units (the modern form of the metric system). with seven base units - second (s), meter (m), kilogram (kg), ampere (A), degrees kelvin (K), mole (mol), and candela (luminous intensity) (cd).

Siliciclastic Rocks - rocks formed by the compaction and cementation of quartz-mineral grains.

Sill –

1) a laminar body of intrusive rock that is parallel to the bedding or pre-existing rock structure, or
2) the semivariance value where a *variogram* levels off.

Silt - soil particles with an effective grain diameter between 0.004 and 0.062 mm.

Siltation - the deposition of fine sediment in the bottom of a stream, lake, or reservoir.

Siltstone - a sedimentary rock comprised predominantly of silt-sized particles.

Sink (as a noun) -

1) any process by which solutes, fluid, colloids, or heat is extracted from a groundwater system, or
2) a general term for a closed depression.

This is related to *doline* or *sinkhole*.

Sinkhole - a closed topographic depression in a karstic landscape, generally varying in size from about 2 to 100 m in depth and 10 to 1,000 m in diameter.

Collapse Sinkholes - form by collapse into a subsurface cavity.

Solution Sinkholes - form by uneven dissolution of the underlying rock or soil. Synonymous with *doline*.

Suffosion Sinkholes - form by loose unconsolidated materials being washed into fissures or caves below.

Skin - a layer or coating that has hydraulic properties different than those of the bulk of the porous medium. Examples of skins include:

1) wellbore skins caused by drilling and/or invasion of drilling mud into the formation,
2) fracture skins caused by mineral precipitation or pore infilling along a fracture, or
3) riverbed skins caused by deposition of fine-grained sediment on the bed.

Skin Effect - a near-wellbore permeability reduction, usually caused during drilling or work-over, that can increase pressure drop between the formation and the well bore and decrease flow rate to/from the well.

Slug Test - a test of media hydraulic properties (typically permeability and sometimes storativity) in which a volume of water is instantaneously added or withdrawn from a well or piezometer and the resulting water level changes over time are measured and analyzed. This is related to *bail test*.

Slurry-Wall - a trench filled with clay (usually bentonite) to block or retard groundwater flow and/or contaminant migration.

SMOW – an acronym for Standard Mean Ocean Water.

Snow - precipitation of frozen water in the form of hexagonal crystals.

Sodium Absorption Ratio (SAR) - a classification of water cation chemistry as it pertains to its usefulness for irrigation.

$$SAR = \frac{\mathrm{Na^+}}{\left(\frac{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}}{2}\right)^{0.5}}$$

where:

$\mathrm{Na^+}, \mathrm{Ca^{2+}}, \mathrm{Mg^{2+}}$ = concentrations of the respective ions in meq/L

Soil -

1) the loose unconsolidated material overlying bedrock (geotechnical engineering terminology), or
2) the upper layer of the regolith in which plants grow, which is a mixture of organic remains (soil scientist definition), or
3) the mixture of organic matter, minerals, gases, liquids, and organisms on the Earth's surface that support the life of plants.

Soil Moisture (or Soil Water) -

1) water in unconsolidated material above the water table, or
2) in particular, water stored in the root zone.

Solidity - the volume of solid grains as a percent of total volume of sediment; solidity is the complement of porosity. Also termed *grain proportion*.

Solute - material dissolved in a liquid (i.e., by a solvent).

Solubility - the propensity of a substance to dissolve in water; the maximum amount of solute that can dissolve in a known quantity of solvent at a certain temperature.

Solution (or Dissolution) - the process by which a solid or liquid becomes dissolved in water.

Solution Channel - a tubular or planar channel formed by dissolution, usually along bedding planes or joints in carbonate rocks.

Solution Pan - see *tinajita*.

Solvent – a substance (usually liquid) capable of or used in dissolving something.

Sorb - see *sorption*.

Soret Effect - the flow of ions from hot zones to cold zones caused by a thermal gradient.

Sorption - the general process by which solutes, ions, and colloids become attached (sorbed) to solid matter in a porous medium. Sorption includes both absorption and adsorption. No new crystalline structure is formed at the surface in the process of sorption.

Absorption -

1) incorporation of an ion or molecule into the interior or surface layer of a mineral structure,
2) integration of one substance into another, or
3) uptake of water or solutes by an organism.

Adsorption - when a dissolved ion, molecule, gas molecule, or colloid becomes attached to the surface of a pre-existing solid substrate.

Sorption Isotherms - relate the amount of solute sorbed on the solid phase (S) to the concentration in the liquid phase (C) at equilibrium for a given constant temperature (hence, the term *isotherm*).

1) Freundlich isotherm: $S = KC^n$
2) Langmuir isotherm: $S = \frac{Q^0 KC}{1+KC}$
3) Linear isotherm: $S = KC$

where for (1), (2), and (3):

K = the partitioning coefficient, typically ml/mg ($L^{-3}M$)

C = the chemical concentration, typically mg/ml (ML^{-3})

n = a fitting factor

Q^0 = the maximum sorptive capacity of the surface

Sorting - the aeolian or alluvial process that selects for certain grain sizes. For example, dune sands have a nearly uniform grain size and are said to be well-sorted. (or poorly-graded).

Source term - description (e.g., location, size, magnitude, duration) of solute, colloid, fluid, or heat that is added to a groundwater system.

Source Control - removing, enclosing, or otherwise eliminating a source of contamination to prevent further subsurface pollution.

Spalling (Spallation) - the breaking off of thin sheets from a rock or mineral surface.

Spallings - material introduced into drilling fluid caused by the release of gases escaping into the well or borehole in which the pressure is lower than in the medium that is being drilled.

Specific Capacity (SC) - the discharge of a well divided by the drawdown in the well. Specific capacity can provide some indication of transmissivity but can vary with discharge rate.

Specific Conductance (EC) or Specific Electrical Conductivity - the ability of water to conduct electricity, typically in micromhos/cm or siemens. It is a function of the ionic concentration. For fresh water free of suspended solids at room temperature, the following approximate relations are utilized

1) TDS (ppm) = 0.65EC (micromhos/cm), and
2) TDS (meq/l) = 0.01EC (micromhos/cm).

Specific Discharge (*q*) - the discharge per unit area normal to flow, same as the *Darcy velocity* (LT^{-1}).

Specific Gravity (G) - the density of a material relative to the density of water at a standard state of temperature, pressure, and salinity.

Specific Heat - the amount of heat it takes to raise a unit mass (or unit volume) of substance a unit increase in temperature. For water, the specific heat is approximately 1 calorie/gram/°C.

Specific Retention - the ratio of the volume of water a porous material will retain against gravity drainage to the total volume of the porous material (-).

Specific Storage (*Ss*) - the volume of water released per unit volume of aquifer for a unit decrease in hydraulic head (L^{-1}).

Specific Surface - the area of a particle, rock, or soil sample per unit mass of solid material (L^2M^{-1}).

Specific Weight - the weight of a substance per unit volume, typically, Nm^{-3}, $(ML^{-2}T^{-2})$.

Specific Yield (*Sy*) - the volume of water that a saturated porous medium can yield by gravity drainage per unit volume of the porous medium.

Spectral Density or Power Spectral Density - the measure of a signal's content versus frequency. Spectral density describes how the flow rates (or variance) of a signal, or a time series, is distributed with frequency.

Speleogenesis - cave formation.

Transverse (Artesian) Speleogenesis - conduit development driven by vertical hydraulic and density gradients across a layered sequence with flow normal (transverse) to bedding. This is common in gypsum karst.

Speleothem - a cave deposit formed by precipitation of minerals from groundwater.

Sphericity - the surface area of a particle divided by the surface area of a sphere of volume equal to the particle.

Split-Spoon - a cylindrical coring device for use in unconsolidated media. It splits in half lengthwise for access to the sample.

Spring - a natural outflow of groundwater to the surface. It may be concentrated or diffuse.

Alluviated Conduit Spring - a rise pool spring with glacial or alluvial material clogging the conduit.

Artesian Spring - a spring in which water flows under artesian pressure through a fissure or orifice in a confining bed.

Contact Spring - a spring where a low-permeability unit outcrops and water flowing through the overlying unit discharges to the surface.

Fault Spring - a spring that discharges from a fault. Commonly one where the fault movement has juxtaposed permeable and low-permeability units near the land surface.

Helocrene Spring - a spring that issues from low-gradient wetlands with indistinct multiple sources from shallow, unconfined aquifers.

Hypocrene Spring - a buried spring where flow generally does not meet the surface because of the discharge is consumed by evaporation or transpiration.

Limnocrene Spring - a spring that discharges into a lake or pond.

Open Conduit Gravity Spring - a spring that discharges from a cave mouth, sometimes blocked by talus.

Rheocrene Spring - a spring that discharges into one or more stream channels.

Rise Pool Spring - a spring that discharges from shallow flooded karst conduits.

Vauclusian Spring - a fountaining spring fed by a shaft or cave system that at times receives more flow at its upgradient end than it can carry at normal pressure. The name comes from the Fountain Vaucluse in France.

Spring Magnitude - measures of spring discharge.

1) A first-order spring has maximum discharges of over 100 cubic feet per second (≅2.8 m/s).
2) A second-order spring has maximum discharges between 10 and 100 cubic feet per second (≅0.28 to 2.8 m/s).
3) A third-order spring has maximum discharges between 1 and 10 cubic feet per second (≅0.028 to 2.8 m/s).

Spring Reliability (or Permanence) - an indication of whether the spring is perennial, intermittent, or ephemeral.

Springshed - the area of land drained by a single spring or group of springs.

Stagnation Point - a place in a groundwater flow field where, at a given time, the water velocity is zero.

Stalagmite - a columnar speleothem growing upwards from the floor of a cavity.

Stalagmos - from Greek, meaning dripping.

Stalactite - a columnar speleothem growing downward from the roof of a cavity.

Standard Deviation (σ) - the measure of the spread of a distribution about the mean. The standard deviation is equal to the square root of the variance (σ^2). This is related to *standard error of the mean*.

Standard Error (of the Mean) - describes the variability that can be expected in the means of samples by repeated sampling from the same population. Standard error of the mean is always less than the *standard deviation* because it is the quotient of the standard deviation and the square root of the sample size.

Static Water Level - the level of water in a well that is not affected by pumping.

Stationarity - a property (e.g., permeability) with no systematic statistical trend with space (or time). A special term is *weak stationarity*, where only the mean and covariance are stationary.

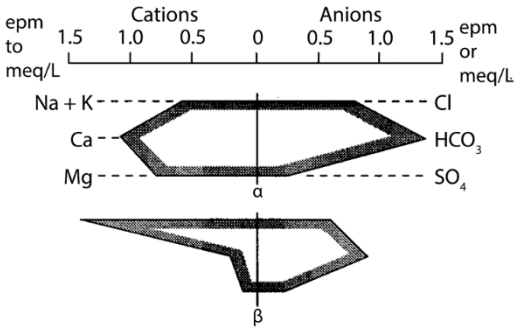
Steady State - the condition in which hydraulic head and flow rates in a groundwater system are not changing with time.

Stenothermal - only tolerant of a narrow range of temperatures. For instance, a variety of organisms inhabiting springs are stenothermal. This is related to *eurythermal*.

Step Drawdown Test - a pumping test in which the rates of drawdown are observed for several levels of constant (generally, increasing) pump discharge. Step drawdown tests are often used to determine well efficiency.

Steppe - vast tracts of land in southeastern Europe and west-central Asia, generally level and without forests.

Stiff Diagram - a graphical means of displaying ratios (epm or meq/L) of the principal ionic constituents in water. It used to display hydrochemical facies and salinities on maps.



Stiff Diagram

Streaming Potential - electrical potential difference occurring as a result of groundwater flow.

Stochastic - pertaining to variables having a random probability distribution.

Stochastic Process - a family of random (or regionalized) variables that is dependent upon another parameter such as space or time.

Stokes-Brinkman Equations - used for computing effective permeability in karst systems. For single-phase, incompressible fluid flow in a mixed free-flow and porous medium, the equation is as follows.

$$\nabla p = -\mu k^{-1} v + \nabla \cdot \mu^* (\nabla v + \nabla v^T) \text{ and } \nabla \cdot v = 0$$

where:

p = fluid pressure ($ML^{-1}T^{-2}$)

v = fluid velocity (LT^{-1})

k = permeability tensor (L^2)

μ = fluid dynamic viscosity ($ML^{-1}T^{-1}$)

μ^* = *effective* fluid viscosity, which depends on properties of the porous medium, tortuosity and porosity, and can be either smaller or greater than μ

Stokes Law - an empirical formula that expresses the rate of settling of (spherical) particles in a fluid.

Storage - water contained within an aquifer or within a surface-water reservoir.

Storage Coefficient - see *storativity*.

Storativity (*S*) - the volume of water released per unit area of aquifer for a unit decline in head. In a confined aquifer, *S* is the specific storage (*Ss*) times aquifer thickness; in an unconfined aquifer, *S* is essentially equal to the specific yield or the effective porosity.

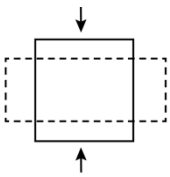
Storm Drain - a pipeline or trench that carries away excess rain, drainage, or surface water.

Strain - a change in the relative configuration of the particles of a solid substance in response to an applied stress.

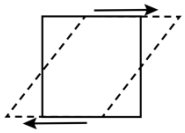
Elastic Strain - strain that is directly proportional to the stress.

Inelastic Strain - strain that is *not* directly proportional to the stress.

Pure Shear Strain - a case where extension occurs along both axes such that $x' = kx$ and $y' = k^{-1}y$, as shown in the following figure.



Simple Shear Strain - particles are displaced only in one-direction or $x' = x + 2sy$, and, $y' = y$ where s is a constant, as shown in the following figure:



Stream - a flowing body of water that is generally confined to a specific channel or channels.

Affluent Stream - a stream that flows toward or into a larger stream or a surface water body.

Effluent Stream - a steam that is receiving baseflow.

Ephemeral Stream - a stream that flows only briefly after rainfall events. Ephemeral streams are generally above the water table and are commonly *losing streams*.

Gaining Stream - a stream that increases in discharge in the downstream direction along its channel because of groundwater inflow.

Influent Stream - a stream with its water flowing into the groundwater system.

Intermittent Stream - a stream that typically does not flow all year long, usually flowing only in the wet season.

Losing Stream - a stream that loses discharge in the downstream direction along its channel.

Perennial Stream - a stream that flows all year long.

Sinking Stream - a stream that loses discharge because its water is infiltrating into the ground.

Streaming Current - an electrical current caused by the flow of ions that may, in turn, be caused by a pressure (or head) gradient.

Streamline (ψ) - the line taken by a packet of water in a flow system, in either groundwater or surface water.

Stream Power Index (SPI) - a measure of the erosive power of flowing water. SPI is based on the slope and the contributing area and can correlate with groundwater recharge.

Stream Tube - the volume between two flow lines through which fluid flows.

Stress - force per unit area.

Effective Stress (σ) - the *grain-to-grain* stress or stress passed through the solid particles of a material.

Neutral Stress - synonymous with fluid pressure because this stress is exerted equally in all directions.

Normal or Total Stress (σ) - the stress exerted by the total weight of materials above a point. Also equal to the stress normal to a plane. Also called the *geostatic stress* or *geostatic pressure*.

Preconsolidation Stress - the maximum antecedent effective stress to which a sediment or rock has been subjected.

Stress Field - a three-dimensional region of a solid continuum subjected to forces of either uniform or varying magnitudes and directions.

Shear Stress (τ) - the stress parallel to a plane.

(Vertical) Seepage Stress - the stress transferred from flowing water to the porous medium by viscous friction. The vertical seepage stress is equal to the difference in head at the top and bottom of a stratum times the unit weight of water.

Stygobites - obligate aquatic cave organisms. Obligate means only able to exist under, or restricted to, one set of environmental conditions.

Stygofauna - cave animals, which includes animals restricted to caves (troglobites, which includes stygobites), those that spend part of their life cycle in caves (troglophiles), and visiting animals (trogloxenes).

Subcutaneous Zone - see *epikarst*.

Subflow - flow into a sedimentary basin at some unspecified depth from the surrounding highlands, commonly through fracture systems. Subflow could also include interbasin flow.

Subirrigation - a technique where irrigation water is applied below the ground either by raising the water table into the root zone or by use of a perforated or porous pipe that discharges directly into the root zone.

Sublimation - the process by which a solid material transforms into the vapor phase without going through the liquid phase.

Subsidence - the lowering (vertical downward movement) of the vertical position of a point at or below the ground surface relative to a defined datum. Small-scale horizontal movements may be present. This *sinking* or *settlement* of the land surface can be caused by a number of processes, including:

1) consolidation from the withdrawal of subsurface fluids (water, oil, or gas),
2) dissolution (e.g., karstification) and collapse,
3) hydrocompaction,
4) mechanical compaction from natural settling or anthropogenic loading,
5) oxidation of soil organic matter,
6) collapse of underground cavities such as mines, or
7) cooling of magmatic bodies.

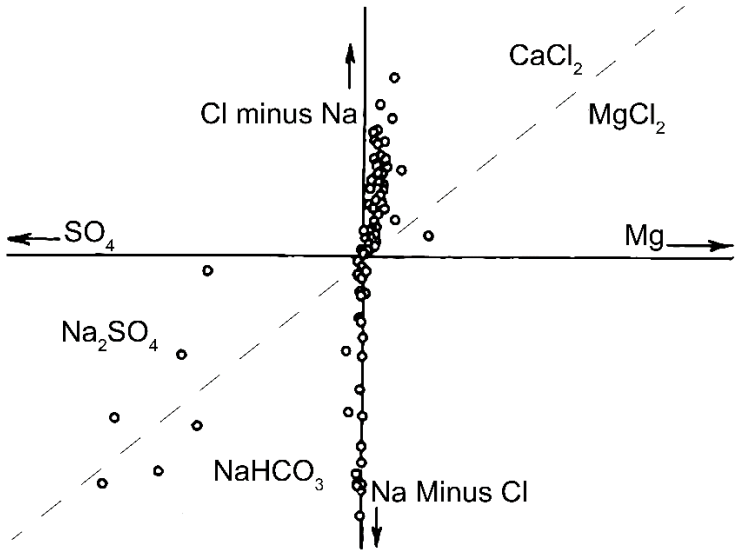
Substrate -

1) the physical surface upon which an organism lives, or
2) the materials that form the bottom of a steam bed.

Substratum - the lower level of sediments in a fluvial fill deposited by vertical accretion, probably during a time of rising geologic base level. Commonly, the substratum fines upwards.

Subcutaneous Zone - see *epikarst*.

Sulin Diagram - a diagram that compares Cl minus Na versus Mg (if positive) or SO_4 (if negative) in ionic ratios (meq/l or epm). The Sulin diagram is used in classification of oil-field waters. Water samples that plot in the $CaCl_2$ range indicate old marine origin, $MgCl_2$ recent marine origin, Na_2SO_4 deep meteoric origin, and $NaHCO_3$ shallow meteoric origin.



Sulin Diagram

Sump - a cave passage that descends below the surface of flowing or standing water.

Supercritical Fluid - A fluid that exists at conditions of pressure and temperature in excess of its critical temperature and pressure (the fluid's critical point), above which it cannot exist as a liquid but only as a dense fluid that combines the properties of gases and liquids.

Surface Tension - the force per unit length along the interface between a liquid and air. The surface tension for air/water at standard temperature and pressure is 72 dynes/cm.

Surface Water -

1) water in streams, rivers, lakes, wetlands, and reservoirs; or
2) US state of Texas' *legal definition*: water of the ordinary flow, underflow, and tides of every flowing water, natural stream, and lake, and of every bay or arm of the Gulf of Mexico. This includes surface water injected in aquifer storage and recovery systems (ASR) and all waters in such water courses

regardless of their origin. It does not include diffused surface water, groundwater, or spring water before it reaches a watercourse.

Surfactant - a soluble compound that reduces the surface tension of a liquid.

Sustainable Yield - see *yield*.

Susceptibility -

Ecological susceptibility – the extent to which an organism or ecological community would suffer from a threatening process or factor if exposed, without regard to the likelihood of exposure.

Magnetic susceptibility - the degree to which a material becomes magnetized in response to an applied magnetic field.

Sustainability -

1) the rates and methods of Earth resource utilization that can sustain a reasonable human population indefinitely at an acceptable standard of living;
2) *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland Commission, 1987, https://eur-lex.europa.eu/EN/legal-content/glossary/sustainable-development.html#:~:text=Sustainable%20development%20was%20defined%20in,to%20meet%20their%20own%20needs').

SVOC (Semi-Volatile Organic Chemicals) - somewhat volatile organic chemicals (e.g., polyaromatic hydrocarbons, polychlorinated biphenyls (PCBs)).

Swallet (or Swallow Hole or Throat) - a place where a sinking stream goes underground; surface flows diverted underground through discrete openings in bottoms of sinkholes or along streams. Also called a *ponor*.

System -

1) a system is a set of interacting elements that form an integrated whole, or
2) any organized assembly of resources and procedures united and regulated by interaction or interdependence to accomplish a set of specific functions.

Distributed System - a system that considers spatial distributions within its boundaries.

Lumped System - a system that does not consider spatial variability, also called a *black box system*.

T

Tafone (Tafoni is the plural) - large hollow or cavern on an outcrop caused by wind or water scouring and/or crystallization of salts.

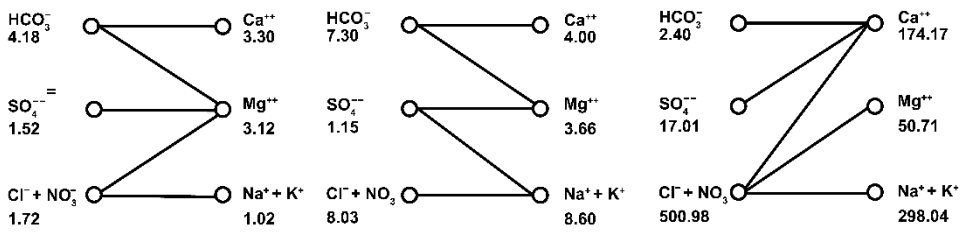
Take -

1) to harass, harm, pursue, or hunt, or
2) shoot, wound, kill, trap, capture, or collect individual members of a listed species, or attempt to engage in such conduct (from the US Endangered Species Act 16 U.S.C. 1531-1544 (US Fish and Wildlife Service (1973)).

Talik - a zone of unfrozen ground above, within, or beneath permafrost.

Tamers' Point - the end point of a process in carbon isotope evolution of dissolved inorganic carbon (DIC) by simple binary mixing of soil CO_2 and carbonate solid.

Taussig Diagram - combines equivalent concentrations (meq/L or epm) of ion pairs in a fixed sequence to identify changes in the hydrochemical facies, but not directly salinity, along flow paths. In the diagram, the HCO_3^- is matched first with Ca^{++}, then Mg^{++}, $Na^+ + K^+$, the excess of cation (Ca^{++} or Mg^{++} or $Na^+ + K^+$ is then matched with $SO_4^{-2}$and then $Cl^- + NO_3^-$, and so on.



Examples of Taussig diagrams (Mandel & Shiftan, 1981). Left: $Ca - Mg - HCO_3^-$ facies (TDS ≅520 mg/L); Center: $Na - Cl - HCO_3^-$ facies (TDS ≅1120 mg/L); Right: $Na - Ca - Cl$ facies (TDS ≅29,800 mg/L).

Taylor Microscale (or Turbulence Length Scale) - a scale used to characterize a turbulent fluid flow. It is an intermediate scale at which fluid viscosity significantly affects the dynamics of turbulent eddies in the flow. This is related to the *Kolmogorov microscales*.

Technology - a modification of the natural world to fulfill human needs or desires.

Temperature - the degree or intensity of heat in a substance, especially as expressed according to a comparative scale and shown by a thermometer or perceived by touch.

Tensiometer - a device that measures soil water matric potential.

Tension - the state where the forces are directed outward (or away from each other).

Tensor - a number whose magnitude varies with direction (e.g., *hydraulic conductivity*, *stress*).

Teratogen - a substance that causes malformations of an embryo or fetus. This can be a chemical substance, a virus, or ionizing radiation.

Terrace - a level surface in a fluvial system that reflects former changes in base level. Three major subcategories of terraces are:

Cut Terraces - reflect a period of lowered base level (accompanied by stream incision and lateral erosion).

Fill Terraces - reflect a period of deposition during rising base levels.

Strath Terraces - terraces that are cut into bedrock rather than alluvial materials.

Terrain - a region, tract, or environment denoted by its physiographic features.

Terrane - a fault-bounded area with distinct geology.

Tertiary Treatment - reduction or removal of special chemical trace metals in (sewage) effluent from secondary treatment.

Terzaghi's Law (or Rule) - the total stress (σ) at a given depth in the system is equal to the sum of the effective stress (σ') and the pore fluid pressure (p) as shown in the following equation. We assume that changes in the total stress are initially compensated for by an equivalent change in the fluid pressure.

$$\sigma = \sigma' + p$$

Texture - the percentage of clayey, silty, and sandy materials in the mineral fraction of a soil.

Thalweg - the line connecting the maximum depth (lowest points) of cross sections along a stream or valley, whether underwater or not.

Theis Equation - the equation for radial transient flow to a well in an idealized confined aquifer as shown in the following equation.

$$s = \frac{Q}{4\pi T} \mathrm{W}(u) \qquad \text{(n)}$$

where:

s = drawdown (L)

Q = pumping rate (L^3T^{-1})

T = transmissivity (L^2T^{-1})

$\mathrm{W}(u)$ = the well function with $u = (r^2S)/(4T)$ (–)

r = distance from the pumping well (L)

S = storativity (–)

t = the time since pumping began (T)

Thenardite - A white or brownish orthorhombic mineral (Na_2SO_4) that commonly occurs in connection with saline/alkali lakes.

Thermal Conductance - heat flow caused by temperature differences in a solid or a porous medium. This is related to *Fourier's Law*.

Thermal Conductivity (λ or κ) - the rate of heat flow per unit area for a unit thermal gradient normal to that area. Analogous to *hydraulic conductivity* in fluid flow.

Thermocline - the zone in a lake that separates the warm shallow water (epilimnion) from the deeper cold water (hypolimnion).

Thermo-Electricity - flow of electricity due to a thermal gradient.

Thermo-Osmosis - flow of fluid through a membrane against an osmotic pressure gradient due to a thermal gradient.

Thermophile - organisms that thrive at relatively high temperatures in the range of 41 and 122 °C (e.g., microbes living in thermal springs and fumaroles).

Thermal Pollution - discharge of waste heat into the surroundings (e.g., air and bodies of water).

Thiem Equation - equation for steady radial flow to a well in an idealized confined aquifer as represented by the following equation.

$$h_2 - h_1 = s_1 - s_2 = \frac{Q\, ln(r_2/r_1)}{2\pi T}$$

where:

r_1, r_2 = distance from the pumping well with $r_2 > r_1$ (L)

h_1, h_2 = head, respectively, at r_1 and r_2, with $r_2 > r_1$ (L)

s_1, s_2 = drawdown, respectively, at r_1 and r_2, with $r_2 > r_1$ (L)

Q = pumping rate (L^3T^{-1})

T = transmissivity (L^2T^{-1})

Third-party Impacts – Direct and indirect economic, social, or environmental effects of a water transfer to a party other than the seller or buyer including other water rights holders.

Thixotropic - a fluid that shows a limited decrease in viscosity with time under suddenly applied (constant) shear stress. Drilling mud is a good example.

Thornthwaite Approximation - an empirical method of estimating monthly potential evapotranspiration, for a month of 30 days and 12 hours of daylight, using air temperatures as an index of the energy available for the process as shown in the following equation.

$$PET_i = 1.6\left(10\frac{T}{I}\right)^a$$

where:

PET_i = the potential evaporation for month i (LT^{-1})

T = mean monthly temperature for month i (°C)

I = the local heat index, $I = \sum_{i=Jan}^{Dec}(0.2\ T^{1.514})$ only including months when $T > 0$ °C

a = $\left(6.75x10^{-7}\ I^3\right) - \left(7.71x10^{-5}\ I^2\right) + \left(1.79x10^{-2}\ I\right) + 0.49239$

PET_i is modified for different hours of daylight (h) and number of days in a month (N) by multiplying by (h/12)(N/30).

Threshold Effect Level - the level of a contaminant above which negative biologic effects can sometimes occur. This is related to *probable effect level*.

Tidal Efficiency (TE) - the degree to which changes in hydraulic head in an aquifer or a well reflect changes in broad scale loading of the Earth surface such as occurs when tides rise and fall. This is related to *barometric efficiency* (BE).

Tile Drain - a drain collecting subsurface water and routing it to a drainage ditch, stream, or wetland. Initially, short segments of clay or cylindrical concrete tiles were used; modern tile drains typically use corrugated, perforated plastic pipe.

Time Drawdown Test - see *Cooper-Jacob equation*.

Time of Travel (TOT) - time required for a contaminant (e.g., chemical, pathogen, colloid) to move from a specific point to a well, spring, or other designated location.

Tinajita - a broad, shallow basin formed by biochemical dissolution on flat bedrock by standing water. They start as small pits and grow laterally, often having an overhanging rim Also called *tinaja*, *solution pan*, and *etched pothole*.

TMDL (Total Maximum Daily Load) -

1) a regulatory term in the US Clean Water Act that describes a value of the maximum amount of a pollutant that a body of water can receive and still meet water quality standards, or
2) an allocation of that water pollutant deemed acceptable for the subject receiving waters, or
3) the maximum amount of point and non-point source pollutants a stream or other body of water can take in during a single day and still support its designated uses.

Tomo - a shaft or hole formed by the action of water on limestone.

Topographic Position Index (TPI) - an algorithm used to measure topographic slope positions and to automate terrain shape classifications.

Topographic Wetness Index (TWI) - is used to calculate the topographic control of hydrological processes and reflects the possible infiltration of groundwater caused by the effects of topography.

Toponym - the general term for a proper name of any geographical feature.

Topstratum - the upper level of sediments in an alluvial fill, deposited by lateral migration of the stream over the floodplain.

Tortuosity (T or τ) - actual length of a groundwater flow path (L_a) divided by the straight-line distance between the ends of the flow path (L) or the reciprocal of this ratio. Several variations of the formula are used in the literature for calculating this ratio as shown in the following equation.

$$\tau = \frac{L_a}{L}, \ \tau = \left(\frac{L_a}{L}\right)^2, \text{ or their reciprocals.}$$

Thus, when referring to tortuosity, the applicable relationship needs to be defined.

Total Dissolved Solids (TDS) - the sum of all organic and inorganic dissolved matter in water. This is related to *specific conductance*.

Measured Total Dissolved Solids (TDS (mg/L)) - the sum of dissolved ions $(Ca + Na + K + Mg + Cl + SO_4 + NO_3) + 0.508 * HCO_3 + SiO_2$ (if available). This is used in the USA by the Texas Water Development Board to account for CO_2 loss that can occur in the evaporative method for estimating TDS, which was the method used in early water chemistry reports. Calculating TDS (mg/L) as the sum of the dissolved ions $+SiO_2$ (if available) is the preferred method.

Totalized Flow - same as *cumulative flow*.

Toxicant - a nonregulatory description of a toxic or hazardous contaminant.

Trace Element – an element found in only minor amounts (concentrations less than 1.0 milligram per liter) in water or sediment (e.g., arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc).

Tracer - a dissolved or suspended substance introduced into or naturally occurring in groundwater that is used to estimate flow rate and direction. Some natural tracers are applied artificially in tracer tests (e.g., $NaCl$).

Applied (Artificial) Tracer - does not occur naturally in a flow system (e.g., SF_6, microspheres, rhodamine dyes, short-lived radioactive traces such as ^{82}Br).

Conservative Tracer - does not interact with the solid matter (i.e., there is no sorption, dissolution, precipitation) and does not decay radioactively or biogenically (e.g., Cl^-, florescent dyes).

Natural or Natural Environmental Tracer - has been transported to or created within the atmosphere or subsurface under natural processes (e.g., $^{14}C, Cl^-, ^{2}H, ^{18}O, \ ^{87}Sr/^{86}Sr$, radium).

Tracer Test - a tracer (solute, suspended or floating matter, or heat) is artificially or naturally induced to evaluate the rate and direction of groundwater flow. Common tracers include *salt*, *fluorescent dyes*, and *neutrally buoyant microspheres*.

Transient - the condition in which properties of a system vary with time.

Transitional Flow - flow that is a mixture of laminar and turbulent flow.

Transmissivity (*T*) - the discharge through a unit width of the entire saturated thickness of an aquifer for a unit hydraulic gradient normal to the unit width sometimes termed the *coefficient of transmissibility*, in the USA, commonly reported in gallons per day per foot (L^2T^{-1}).

Transpiration - the process by which plants (and animals) release water vapor into the atmosphere.

Transition Zone -

1) the zone in an aquifer where the water salinity changes from < 1,000 to > 10,000 mg/L (e.g., the Edwards Aquifer of Texas), or
2) the zone in caves where the microclimate is affected by surface climate events and the fauna is seldom rich in troglobites.

Transport - the movement of solute, suspended matter, or heat in a porous medium, in a surface stream, or through the atmosphere.

Facilitated transport - groundwater transport in which the mobility of a contaminant is increased relative to "expected" retardation by adsorption to subsurface solids.

Travertine - freshwater limestone that forms at springs, in caves, or other environments where rapid precipitation of calcite occurs.

Tremie Pipe - a narrow pipe or tube used to emplace material in the annular space around a well casing.

Trend Surface Analysis - a mathematical method of separating map data into two components: that of a regional nature and local fluctuations.

Tributary - a stream that flows into another body of water or into a (larger) stream.

Triple Point - the temperature and pressure where water can coexist in all 3 states (ice, water, and vapor). This is T = 273.16 °K (0.01 °C) and p = 611.66 Pa.

Tritium – the radioactive isotope of hydrogen (^3H) with a half-life of 12.43 years.

Tritium Unit (TU) - a measure of the concentration of tritium (^3_1H) equal to one ^3_1H in every 1,018 atoms of H or 3.24 picocuries/liter.

Troglobites - an animal that completes its entire life cycle in the cave habitat. They exhibit morphological features (e.g., loss of eyes and surface pigmentation) that indicate a long evolutionary history in cave environments.

Troglophile - an animal that completes its life cycle in both cave and non-cave environments.

Trogloxenes - an animal that visits cave habitats but does not complete its life cycle there.

Trona - a natural mineral salt of sodium (sodium sesquicarbonate) crystallized from saline water by evaporation.

Truncated Data - these data that are limited because the spatial or temporal scale of the data set is insufficient.

Tufa - generally a whitish, crumbly freshwater carbonate deposit precipitated in flowing springs as a result of CO_2 loss.

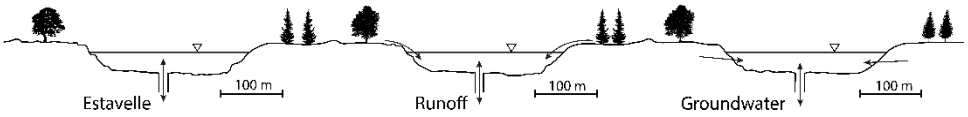
Tuff - consolidated or cemented volcanic ash and lapilli.

Turbid - a liquid that is thick or opaque with suspended matter.

Turbostratic - type of fabric in which clay-mineral particles are in aggregates within which the orientation is preferred and between which the orientation is random.

Turbulent Flow - flow where fluid particles move along irregular paths and cross streamlines. Momentum can be exchanged between different portions of the flow field.

Turlough - disappearing lake found mostly in limestone areas of Ireland. They can be sourced by flow from estavelles, surface streams/runoff, or groundwater flow from epikarst and shallow underlying strata. Pronounced "tour-lock."



TVD (Total Vertical Depth) - the vertical distance from the wellhead to the bottom of the well. For directionally drilled wells, the TVD is smaller than the total drilled length of the well.

U

Unconfined - refers to an aquifer that has a water table and implies direct contact of the water table to the atmosphere (through the vadose zone).

Underfit Stream - a stream that occupies a valley that was carved by a previous stream of greater discharge.

Underfit Basin - a sedimentary basin with great (e.g., > 200m) depth to groundwater that implies the basin could be transmitting more water than it currently does. This is related to *flow capacity*.

Underflow -

1) the flow of groundwater in the alluvial materials beneath and immediately adjacent to a stream and flowing in the same general direction as the stream, or
2) in karstic systems, an underflow conduit or system is a deeper flow path that generally flows at all times (in contrast with an overflow conduit). These are typically closed systems with respect to the atmosphere.

This term is commonly misused as a term for interbasin groundwater flow, a regional component of flow, subflow, or any deep flow path.

Underflow Conduit - a permeable deposit underlying or adjacent to a surface streamway, more or less definitely limited at its bottom and sides by rocks of relatively low permeability, that contains groundwater that flows approximately downstream.

Underground Source of Drinking Water (USDW) - an aquifer or portion of an aquifer that

1) supplies any public water system,
2) contains a sufficient quantity of ground water to supply a public water system,
3) currently supplies drinking water for human consumption, or
4) contains fewer than 10,000 mg/l total dissolved solids, and
5) is not an exempted aquifer.

Underpressures - fluid pressures lower than predicted hydrostatic pressure. These are found in recharge zones and in areas where there is osmotically induced fluid flow.

Unified Soil Classification System - a standardized classification system of soils based upon grain size, moisture content, and Atterberg limits.

Uniformity Coefficient – see *coefficient of uniformity*.

Unit Hydrograph - the response of a direct runoff streamflow hydrograph generated by 1 inch (or 1 centimeter) of excess rainfall spread uniformly over the drainage area at a constant rate for an effective duration.

Unit Weight - the weight of a substance divided by its volume, typically in pounds per cubic foot, or kilograms meter per square second, kg m s^{-2}, (MLT^{-2}).

Unsaturated - the condition when the porosity is not completely filled with water.

Unsaturated Flow - flow of water in a porous medium in which the pores are not entirely filled with water.

Unsaturated Zone - generically, is roughly, but not precisely, equivalent to the vadose zone. This is the zone above the saturated portion of the capillary fringe where the pores are generally filled with both air and water and the fluid pressure is less than atmospheric.

Urbanization - the changing of a landscape to an urban or suburban setting, usually with the addition of pavements, buildings, and utility systems.

Urban Runoff - storm water from city streets and gutters containing litter, organic, and bacterial wastes.

Urey Reaction - $CaSiO_3 + CO_2 = CaCO_3 + SiO_2$, expresses the weathering of silicates in a CO_2-rich setting.

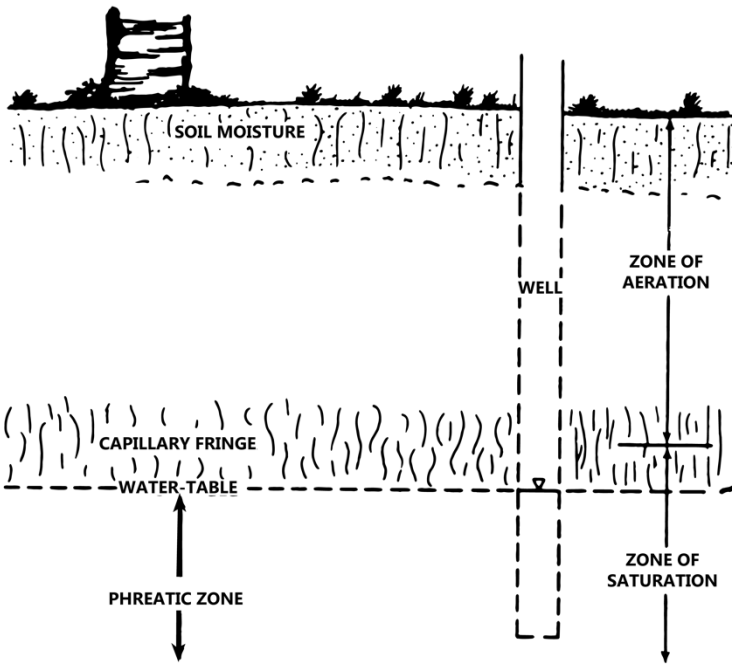
Usiglio-Sequence - the order in which minerals precipitate by evaporation of sea water: First calcite, then gypsum, followed by halite, and finally by K and Mg salts (e.g., sylvite).

Uvala - a closed karst depression formed by enlargement of smaller sinkholes that intersect to form a usually elongated sinkhole larger than the typical doline.

V

Vadose Water - water above the water table where the fluid pressure is less than atmospheric.

Vadose Zone - the zone above the water table where the fluid pressure is less than atmospheric pressure as shown in the following figure.



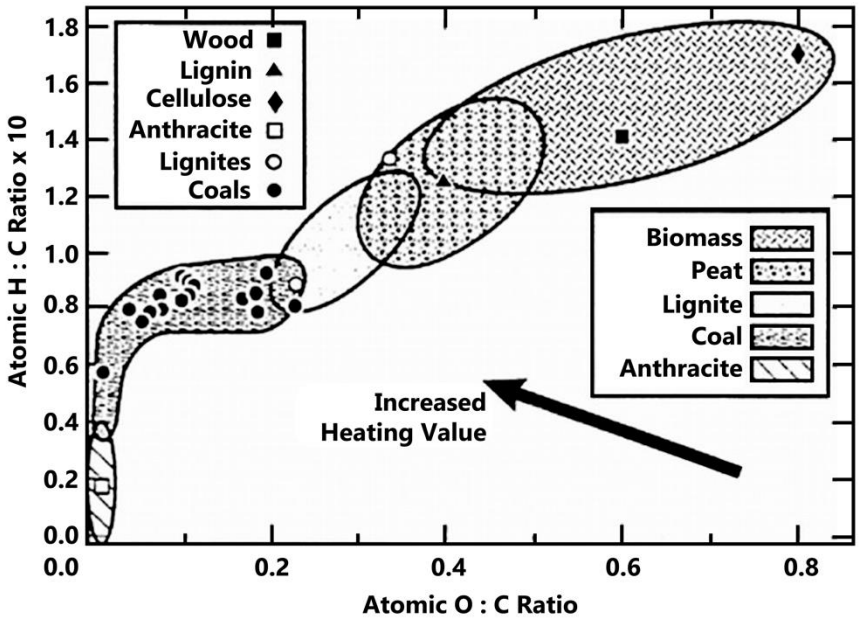
Vadose zone includes the zone of aeration and the capillary fringe.

Valence - the number of electrons in an atom that can be given up to form chemical bonds or react with another atom or group of atoms.

Valley Fill- unconsolidated sediment deposited by any agent (water, wind, ice, mass wasting) that fills or partly fills a stream valley

Van Genuchten Equation - a model for the soil-water content versus pressure head curve that is used to predict hydraulic conductivity within the unsaturated zone (Van Genuchten, 1980).

Van Krevelen Diagram - a graphic used to assess the origin and maturity of kerogen (solid, insoluble organic matter in sedimentary rocks) and petroleum (crude oil) as shown in the following figure. The diagram cross-plots the hydrogen/carbon atomic ratio as a function of the oxygen/carbon atomic ratio.



Van Krevelen diagram
(https://en.wikipedia.org/wiki/Van_Krevelen_diagram↗)

Van't Hoff Relation - the effect of temperature on the equilibrium constant (i.e., K_T at the temperature of interest) as shown in the following equation.

$$\log K_T = \log K_{TR} \left(\frac{\Delta H_R}{2.3R}\right)\left(\frac{1}{T} - \frac{1}{TR}\right)$$

where:

K_{TR} = equilibrium constant at the reference temperature (–)

ΔH_R = the standard state enthalpy (ML^2T^{-2})

R = gas constant, typically expressed as 8.314 J mol^{-1} K^{-1}, ($ML^2T^{-2}\Theta^{-1}$)

T = the temperature of interest (Θ)

TR = the reference temperature (Θ)

Vapor- the gaseous form of any substance.

Vapor Pressure Deficit - difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated.

Vaporization - the transfer of chemical mass from a liquid phase (e.g., LNAPL; Light Non-Aqueous Phase Liquid) to the adjacent air phase.

Variability (of Spring Flow) - the ratio of its annual fluctuation in spring discharge to its average discharge as shown in the following equation.

$$V = 100\left(\frac{a-b}{c}\right)$$

where:

V = the variability (in percentage)

a = the maximum discharge

b = the minimum discharge

c = the average discharge.

This is related to *spring reliability* (or *permanence*) with the following for different ranges of V:

constant spring: $V < 25$ percent

subvariable spring: 25 percent $< V <$ 100 percent

variable spring: $V >$ 100 percent

Variable (dependent) - a mathematical quantity of unknown value until the mathematical expression is solved.

Variance (σ^2) - a measure of the spread of a distribution, defined as shown in the following equation.

$$\sigma^2 = \sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n}$$

where:

n = the number of samples

x_i = the sample value

$\bar{x}$ = the mean of the sample values

The square root of the variance is the standard deviation.

Variogram - a plot of semivariance as a function of lag along a support (typically, lag distance). The nugget is the semivariance at a zero-correlation length; the sill is the maximum semivariance or the plateau of the semivariogram; the correlation length (or range) is the distance over which variables are correlated (i.e., the distance where the semivariogram plateaus).

Vector - a number that has both magnitude and a direction (e.g., velocity, gradient).

Vertisols - soils that have 30% or more clay, deep wide cracks when dry, and some combination of gilgai microrelief, intersecting slickensides, or wedge-shaped structural aggregates tilted at an angle to the horizon.

Virgin Flow - streamflow that existed or would exist in the absence of human actions.

Viscosity - the internal friction of a fluid or the resistance of a fluid to flow. Water viscosity decreases with increasing temperature (T). To a lesser degree viscosity increases with increased solute concentration. With increased pressure there is negligible change in viscosity for $T < 33$ °C, above 33 °C viscosity increases with increased fluid pressure. Various viscosity definitions are given below.

1) **Dynamic (or absolute) viscosity** (μ) - the ratio of the shear stress divided by the rate of shear ($ML^{-1}T^{-1}$).
2) **Kinematic viscosity** (ν) - dynamic viscosity divided by the density of the fluid (L^2T^{-1}).
3) **Newtonian viscosity** (a perfectly viscous substance) - has a linear relationship between stress and the rate of strain.
4) **Effective viscosity** - the single representative viscosity value for fluid flow under a given set of conditions.

Volatile Organic Compound/Chemical (VOC) - an organic chemical that has a high vapor pressure relative to its water solubility such as benzene, gasoline, and fumigants.

Void - a pore space or other opening in rock or soil.

Void Ratio (*e*) - the volume of the voids divided by the volume of the solids in a porous medium.

Volcanic Water - see *magmatic water*.

Volatilization - the process by which a liquid or solid goes into a gaseous phase. This is a major factor in the attenuation of organic liquids in shallow groundwater systems.

Volatile Organic Compound (VOC) - an organic chemical with a high vapor pressure relative to its solubility in water. Examples include organic solvents, components of gasoline and lubricants, fumigants, among others.

Voxel—Each of an array of volume elements that constitute a three-dimensional space used in computer-based modeling or graphic simulation.

Vug - a cavity in a rock, which may be lined or filled with minerals of different composition from the surrounding rock. Vugs may be formed by dissolution or cooling of magma. The adjectival form is *vuggy* or *vugular*.

Vulnerability -

1) the potential of a system (e.g., an aquifer) to suffer loss or damage, or
2) the tendency or likelihood for contaminants to reach a specified portion of a groundwater system after introduction at some location above the uppermost aquifer.

W

Wadi - a usually, a steep-sided valley, ravine, or watercourse in an arid climate (e.g., North Africa or Arabia) that is dry except after heavy rains or during the rainy season (if there is one).

Wash (or Desert Wash) - a broad, gravelly intermittent stream channel in arid or semi-arid regions that is occasionally swept by torrential flood flows.

Washburn-Bunting Method - calculates effective porosity as a function of mercury injection. The volume of air in the pores of a rock sample at atmospheric pressure is extracted (displaced by mercury intrusion) and then collected in a graduated burette at atmospheric pressure. The volume of air is read directly as the pore volume of the sample.

Wastewater - water that has been used and carries waste from homes, businesses, and industries.

Water ($\mathbf{H_2O}$) -

1) the liquid that descends from clouds as rain and forms oceans, rivers, lakes, streams, glaciers, and flows through the pores and cracks in subsurface materials, or
2) the medium of biology.

This is related to *connate*, *evolved/diagenetic*, *fossil*, *juvenile*, *magmatic*, *mantle*, *metamorphic*, and *meteoric water*.

Water-Bearing Unit - This imprecise term should only be used if it is very carefully defined. In the literature, water-bearing unit has meant an aquifer, a perched aquifer, a permeable zone, a bed of a member of a geologic formation, or a saturated unit of low permeability (i.e., an aquitard). As applicable, use the term *aquifer*, *permeable bed* or *strata*, or *confining unit* (i.e., *aquitard, aquifuge,* or *aquiclude*).

Water Content - there are four ways to express water content.

1) **Gravimetric**: weight of water in a sample divided by the weight of the solids in the sample.
2) **Volumetric**: the percentage of the total sample volume that is filled with water.

3) **Residual**: the water in a sample that cannot be removed by draining or soil suction.
4) **Saturation**: water content when all the pores are filled with water.

Water Equivalent - the depth of water that would be obtained by melting a given thickness of snow.

Water Gap - a deep pass in a mountain ridge through which a stream flows.

Water Market - a formal exchange where water rights or a portion of the volumes associated with those rights are sold, purchased, optioned, or leased for the purpose of conveyance, transfer, supply, or forbearance of changing the legal purpose of use. Water markets are contained within a geographically distinct area and do not include a market for wholesale or retail water transactions.

Water Table - a surface at or near the top of the phreatic zone (zone of saturation) where the fluid pressure is equal to atmospheric pressure. In the field, the water table is defined by the level of water in wells that barely penetrate the phreatic (saturated) zone.

Water-Table Ratio (WTR) - a ratio defining topography-controlled (log (WTR) > 0) versus recharge-controlled (log (WTR) < 0) water tables.

$$\log(WTR) = \log\left(\frac{RL^2}{mKHd}\right)$$

where:

R = recharge rate (LT^{-1})

L = length of the system (L)

m = a unitless constant (8 for a one-dimensional system and 16 for a radial system)

K = hydraulic conductivity (LT^{-1})

H = aquifer thickness (L)

d = relief of the water table (L)

Watercourse - (*legal definition*) a definite stream of water in a definite natural channel, with well-defined bed and banks, from a definite source or sources of supply.

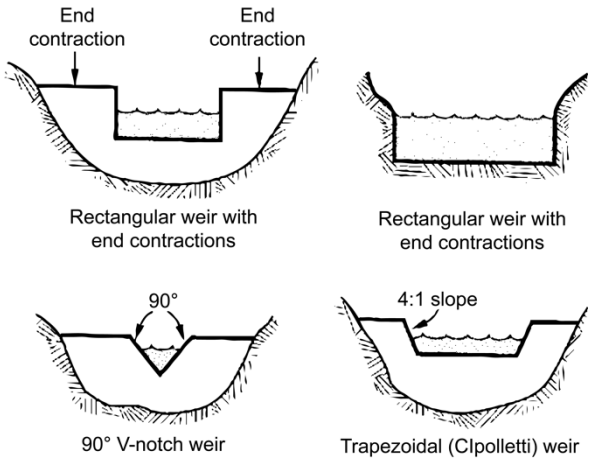
Waters of the United States (WOTUS) - include traditional navigable waters, territorial seas, interstate waters, impoundments, tributaries, adjacent wetlands, and additional waters (i.e., lakes, ponds, streams, or wetlands that do not fit into the other categories but meet certain standards). Tributaries, adjacent wetlands, and additional waters are jurisdictional if they satisfy either the *relatively permanent standard* or *significant nexus standard*:

a) The relatively permanent standard requires relatively permanent, standing or continuously flowing water connected to traditional navigable waters and waters with a continuous surface connection to such relatively permanent or traditional navigable waters.
b) The significant nexus standard means waters that, either alone or in combination with similarly situated waters in the region significantly affect the chemical, physical, or biological integrity of traditional navigable waters, territorial seas, or interstate waters.

Watershed - the area of land drained by a single stream or river or, in the case of karst, drained by a single doline or group of dolines. Watershed and *catchment* are equivalent terms.

Waterway - the path for water to travel across the land (e.g., a channel, lake, stream, river).

Weir - a barricade across a stream. Specially designed weirs are used to estimate stream discharge based on water depth above the weir. Examples include V-notch and rectangular weirs as shown in the following figure.



Weir designs

Well - any artificial excavation or borehole constructed for the purpose of exploring for zones that can produce groundwater, for zones that can receive injected fluids, for monitoring groundwater, or for dewatering a subsurface zone.

Abandoned Well - a well that is no longer in use; has been permanently discontinued; or is in such a state of disrepair that it cannot be used.

Disposal Well - a well that disposes of waste into a subsurface stratum.

Domestic Well- a privately-owned well typically serving one or several homes that supplies potable water.

Flowing Well - a well that discharges at the land surface without pumps or other lifting devices. The aquifer can be confined or unconfined.

Fully Penetrating Well - a well that is open or screened for the entire saturated thickness of the aquifer.

Injection Well - a well into which fluids are being injected.

Monitoring Well - a well that is used for observing groundwater levels and flow conditions, obtaining samples for determining groundwater quality, and for evaluating hydraulic properties of water-bearing strata, essentially the same as an *observation well*.

Observation Well - a well that is used to measure the elevation of the water table or the potentiometric surface. Observation wells are generally of a larger diameter than piezometers and are typically screened or slotted throughout the thickness of the aquifer; essentially the same as a *monitoring well*.

Public-Supply Well - a well that provides water for public use (e.g., a community water system, a transient noncommunity system, or a non-transient, noncommunity system, such as a school).

Recharge Well - a well that is designed to transmit water into an aquifer.

Relief Well - a well that is designed to reduce water pressure in order to prevent water logging of soil, piping, or "blow outs."

Well Casing - see *casing*.

Well Efficiency - the ratio of the drawdown in the formation adjacent to the well divided by the drawdown in the well.

Well Function (W(u)) - the infinite series in the Theis Equation as shown in the following equation.

$$W(u) = -0.577216 - \ln(u) + \sum_{i=1}^{\infty} (-1)^{i+1} \frac{u^i}{i \cdot i!}$$

where:

$u = \frac{r^2 S}{4Tt}$

r = distance from the pumping well (L)

S = storativity (-)

T = transmissivity (L^2T^{-1})

t = time since the well began pumping at a constant discharge (T)

Wellhead - the physical structure, facility, or device at the land surface from which groundwater flows or is pumped.

Well Log - an accurate record made during or after drilling that shows the value of various parameters (e.g., formation thickness, well diameter, fractures, geophysical properties, geochemical data, or flow data) with depth in the well.

Well Loss - the drop in hydraulic head in a well bore below that in the adjacent aquifer or reservoir created by turbulent flow and by frictional head losses in the well screen and in the gravel pack.

Well Nest - a series of casing completions at different depths {isolated from one another) in the same well or borehole.

Well Point - a portion of a casing that is screened and near the bottom of the well. Some have conical points (drive points) on the bottom that are used when driving a well with downward pressure or manual hammering. Wellpoint systems are commonly used in shallow dewatering projects.

Well Screen - a portion of a well casing that is perforated or slotted to allow water to pass.

Well Stimulation - various processes used to clean the well bore, enlarge flow channels in porous or fractured media, or increase pore space in the target interval making it possible for fluids to move more readily into or out of the aquifer. Stimulation methods include surging, jetting, blasting, acidizing, and hydraulic fracturing.

Well Yield - the discharge of well at (nearly) steady flow (L^3T^{-1}).

Well Volume - the volume of water in the well casing from the static water level to the bottom of the well.

Wellhead Protection Area - a designated surface and subsurface area surrounding a well or a well field through which contaminants could pass and eventually reach the aquifer that supplies the well or well field.

Wetland - areas under or contiguous to open water or with a shallow water table, including swamps, marshes, bogs, fens, wet meadows, river overflows, mud flats, and natural ponds. Wetlands are characterized by water-loving vegetation (phreatophytes or, in areas with brackish water, halophytes).

Wettability - the tendency for a fluid to be attracted to a surface in preference to another fluid (e.g., water is generally the wetting fluid in rock and soil in preference to air or non-aqueous phase liquids).

Wetted Perimeter - the length of the wetted contact between a conveyed fluid and the open channel or closed conduit carrying it, measured at right angles to the flow direction.

Wiener Bounds - theoretical upper and lower limits for a parameter (e.g., thermal conductivity or diffusivity) for three-dimensional assemblage of two components (e.g., sand grains and water or sandstone and shale). The bounds are, respectively, the arithmetic and harmonic mean values.

Wilting Point - the soil moisture level below which a type of plant can no longer extract water from the soil. The plant then suffers loss of turgor (i.e., it wilts).

Winland Equation - is used in petroleum reservoir studies that relate to capillary pressure, permeability, and porosity as shown in the following equation.

$$\log r_{35} = 0.732 + 0.588 \log(k) - 0.88641 \log(\emptyset)$$

where:

r_{35} = the pore-throat radius at 35 percent mercury saturation in μm (micrometers)

k = air permeability in mD (millidarcies)

$\emptyset$ = porosity (percent)

Winters Doctrine - a USA doctrine stating that the federal government holds water rights on Native American reservations for purposes of making the land productive.

Work - the transference of energy that occurs when a force is applied to a body that is moving in such a way that the force has a component in the direction of the body's motion, or the line integral of the force over the path taken by the body.

X

Xerophyte - a plant that thrives in arid or semiarid conditions; a plant adapted to dry conditions; or a desert plant.

Y

Yield -

1) generically, the amount of water pumped from a well (or bore). The dimensions of yield are volume per time (L^3T^{-1}), or
2) total runoff, or
3) the amount of material produced by a specific process (e.g., BOD removed)

In Australia, a narrower definition is used for well yield: Yield does not exceed a specified percentage (typically ≈2 percent) of the column of water above the base of the aquifer. This assumes that the well is fully penetrating and screened over all permeable intervals of the aquifer.

Definitions of yield pertaining to other entities follow.

Available Yield - the volume of water that is considered acceptable for permitted extraction from an aquifer because it is

1) scientifically feasible,
2) within the bounds of effective yield quantification, and
3) acceptable to the community of stakeholders.

Consensus Yield - the acceptable extraction volume from an aquifer or aquifer system as determined by the inter-related elements of both local and regional hydrologic regimes within the context of the specific preferences of the affected stakeholders. The process involves stakeholders identifying different management goals; scientists and engineers calculating the amount of groundwater available for use for each of the management goals; and the stakeholders reaching consensus (however consensus is defined) about the amount of groundwater available for use.

Dynamic or Effective Yield - the amount of groundwater available for use that is allowed to change over time in response to changing policy goals and an increased understanding of the resource.

Effective Yield -

1) the amount of water that can be extracted from an aquifer under a given set of operating conditions while meeting community-defined performance metrics or constraints over a planning horizon, or
2) an implementable and quantifiable volume of water that can be allocated from an aquifer.

Firm Yield - the amount of water that can be pumped or extracted daily during the drought of record.

Mining Yield - the appropriate rate of pumping from an aquifer that is receiving no or little recharge.

Optimal Yield - the rate of extraction of groundwater from an aquifer, aquifer system, or groundwater basin for various uses that maximizes the time discounted rate of return.

Safe Yield - the volume of water that can be withdrawn annually from an aquifer (or groundwater basin or system) without

1) exceeding average annual recharge,
2) violating water rights,
3) creating uneconomic conditions for water use, or
4) creating undesirable side effects such as subsidence or saline water intrusion.

Sustainable Yield -

1) the volume of water that can be extracted annually from an aquifer or a groundwater basin that can, in conjunction with other available water resources, sustain a reasonable human population indefinitely at an acceptable standard of living and maintain critical natural habitats indefinitely; or
2) development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences (Alley et al., 1999).

Young's Modulus - the ratio of simple tension (or compressive) stress applied to a material to resulting strain parallel to the applied stress. This is related to *bulk modulus*.

Z

Zone (of an Aquifer) - a subdivision of an aquifer that is denoted by particular hydrogeologic characteristic that is not typical of the entire aquifer (e.g., the Boulder zone and the Fernandina permeable zone of the Floridan Aquifer in the USA).

Zone of Aeration - the zone above the water table that has both air and water in its pores. It is generally equivalent to the vadose zone.

Zone of Capture (Contribution) (ZOC) - the three-dimensional region that contributes the groundwater extracted by one or more wells or drains. It is also termed the zone of *hydraulic containment*.

Zone of Endangering Influence (from US Environmental Protection Agency) -

1) The area (or in the case of application for a well permit, the radius) encompassing the lateral distance in which pressure in the injection zone may cause migration of the injection and/or formation fluid into an underground source of drinking water. This is also called the *area of review*.
2) The project area plus a circumscribing area in which the pressure in the injection zone may cause migration of injection and/or formation fluid into an underground source of drinking water. The zone of endangering influence is calculated using the formula in regulations or by a fixed radius of not less than one-quarter mile (402.34 m).

Zone of Influence (ZOI) - areas around a pumping well within which the potentiometric surface (or, in an unconfined aquifer, the water table) has been changed by pumping.

Zone of Saturation - the zone in which all the pores are filled with water. This is essentially the equivalent of the *phreatic zone*.

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3 Common symbols, abbreviations, & acronyms

Dimensional formulae are given in parentheses () with M for mass, L for length, T for time, Θ for temperature, A for current.

ADRE = advection-dispersion-reaction equation
AET = actual evapotranspiration (LT^{-1})
AF = acre-foot
AGU = American Geophysical Union
AIH = American Institute of Hydrology
ASPMI = assessment of low probability material impacts
amsl = above mean sea level (L)
AoR = area of review
API = America Petroleum Institute
ARIMA = auto-regressive integrated moving average
ASCII = American Standard Code for Information Interchange
ASR = aquifer storage and recovery
AVI = aquifer vulnerability index
α = compressibility, typically inverse Pascals ($M^{-1}LT^2$)

BAR = Budyko aridity ratio
BEG = Bureau of Economic Geology
BFI = baseflow index
bgs = below ground surface (L)
BHP = bottom-hole pressure, typically in Pascals or pounds per square inch abbreviated psi ($ML^{-1}T^{-2}$)
BHT = bottom-hole temperature, typically in °K (Θ)
bls = below land surface (L)
BOD = biochemical oxygen demand
BTC = breakthrough curve
BTEX = benzene, toluene, ethylbenzene, xylene
BUQW = base of usable water
β = compressibility of water, typically inverse Pascals ($M^{-1}LT^2$)

CATNIP = cheapest available technology not involving prosecution

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act or the Superfund Act

cfs = cubic feet per second (L^3T^{-1})

COD = chemical oxygen demand

COV = covariance

CV = coefficient of variation

D = diffusion coefficient, also called hydrodynamic dispersion coefficient (L^2T^{-1})

DFC = desired future condition (specific to Texas, USA)

DIC = dissolved inorganic carbon

DNAPL = dense non-aqueous phase liquid

DO = dissolved oxygen

DOC = dissolved organic carbon

DWTR = drinking water treatment residuals (from desalination, specifically reverse osmosis)

EC = electrical conductivity, typically in mhos per meter, or siemens per meter ($M^{-1}L^{-3}T^3A^2$)

EDC = endocrine disrupting chemical

EIS = environmental impact statement

EOR = enhanced oil recovery

EPA = Environmental Protection Agency

ER = electrical resistivity, typically in ohm meters, or siemens meters ($ML^3T^{-3}A^{-2}$)

EM = electromagnetic

ET = evapotranspiration (LT^{-1})

e = void ratio (dimensionless)

FEFLOW = A commonly used finite-element numerical model of grpundwater flow

foc = fraction organic carbon

g = gravitational acceleration (LT^{-2})
GAM = groundwater availability model (specific to Texas, USA)
GCD = groundwater conservation district (specific to Texas, USA)
GDE = groundwater-dependent ecosystem
GIS = geographic information system
GMA = groundwater management area (specific to Texas, USA)
gpm = gallons per minute (L^3T^{-1})
GPR = ground-penetrating radar
GPS = global positioning system
GSA = Geological Society of America
GWQ = groundwater quality

h = hydraulic head, also called head (L)
HBSL = health-based screening level
HSPF = hydrologic simulation program-FORTRAN

IAH = International Association of Hydrogeologists
IWRM = integrated water resource management

k = intrinsic permeability (L^2)
K = hydraulic conductivity (LT^{-1})
κ = thermal conductivity, typically in watts per meter Kelvin ($MLT^{-1}\Theta^{-1}$)
K_d = soil/water partitioning coefficient
KOC = organic carbon-to-water partition coefficient
ka = 1,000s of years (T)
Φ = hydraulic potential, potential energy per unit mass of fluid (ML^2T^{-2})

L = length unit (L)
LEL = lower explosive limit
LNAPL = light non-aqueous phase liquid
LOESS = Locally estimated scatterplot smoothing
λ = thermal conductivity, typically in watts per meter Kelvin ($MLT^{-1}\Theta^{-1}$)

M = mass unit (M)

ma = millions of years (T)

MAE = mean absolute error

MAG = modeled available groundwater (specific to Texas, USA)

MAR = managed aquifer recharge

MCL = maximum contaminant level (ML^{-3})

meq/L = milliequivalents per liter

mg/L = milligrams per liter, chemical activity, or combining power, of an element relative to the activity of 1 mg of hydrogen per liter (ML^{-3})

MODFLOW = a commonly used finite-difference numerical model of groundwater flow

MTBE = methyl tertiary butyl ether

MT3D = a commonly used numerical solute transport model

μ = dynamic viscosity, also called absolute viscosity, typically in poise ($ML^{-1}T^{-1}$)

n = porosity (dimensionless)

NAARD = normalized average annual runoff

NAPL = non-aqueous phase liquid

NIMBY = not in my backyard

NIMTO = not in my term of office

NTRU = nephelometric turbidity ratiometric units

p = pressure, typically in Pascals or psi (pounds per square inch) ($ML^{-1}T^{-2}$)

PAH = polycyclic aromatic hydrocarbon

PET = potential evapotranspiration (LT^{-1})

PFAS = per- and polyfluoroalkyl substances

PFA = per- and polyfluoroalkyl substance

PGMA = priority groundwater management area (specific to Texas, USA)

PI = permeability index

PDSI = Palmer Drought Severity Index

ppm = parts per million

ϕ = porosity (dimensionless)

q specific discharge. also called Darcy velocity (LT^{-1})

Q discharge (L^3T^{-1})

QA/QC quality assurance/quality control

Qw groundwater quality

RCRA = Resource Conservation and Recovery Act

REV = representative elementary (elemental) volume (L^3)

RMSE = root mean square error

ROP = rate of penetration

RTE = rare, threatened, and endangered species (often related to spring, or karstic, groundwater systems)

ρ = density (ML^{-3})

S = storativity (dimensionless)

SAR = sodium absorption ratio

SAV = submerged aquatic vegetation

SRAV = shallow-rooted aquatic vegetation

SC = specific capacity, typically in gpm/ft or L/s/m ($L^3T^{-1}L^{-1}$ or L^2T^{-1})

SDWA = Safe Drinking Water Act

SI = saturation index

SMCL = secondary maximum contaminant level

SMOW = standard mean ocean water

SP = spontaneous potential ($MI^{-1}L^2T^{-3}$)

SPI = standardized precipitation index

SpC = specific conductivity ($M^{-1}L^{-3}T^3A^2$)

Sr = specific retention (dimensionless)

SSC = suspended-sediment concentration

Ss = specific storage (L^{-1})

SVOC = semi-volatile organic chemical/compound

Sy = specific yield (dimensionless)

σ = stress, typically in Pascals ($ML^{-1}T^{-2}$) or p.s.i.

t = time (T)

T = transmissivity (L^2T^{-1})

TCEQ = Texas Commission on Environmental Quality

TD = total depth (L)

TDH = Texas Department of Health

TMDL = total maximum daily load

TDS = total dissolved solids ($M\ L^{-3}$)

TIF = tagged image file

TOC = top of casing elevation (L)

TOT = time of travel

TPH = total petroleum hydrocarbons

TRRC = Texas Railroad Commission

TSS = total suspended solids, typically in mg/L (ML^{-3})

TU = tritium units

TVD = total vertical depth (L)

TWDB = Texas Water Development Board

θ = volumetric moisture content (dimensionless)

UIC = underground injection control

USDW = underground source of drinking water

USGS = United States Geological Survey

VOA = volatile organic acid

VOC = volatile organic chemical or compound, typically in ppm or moles (M)

VSMOW = Vienna standard mean ocean water

WAM = water availability model

WOTUS = waters of the United States

WQ = groundwater quality

ybp = years before present (T)

ψ = matric potential, typically in hectoPascals or millibars ($ML^{-1}T^{-2}$)

z = depth (L)

ZOC = zone of contribution

ZOI = zone of influence

ZOT = zone of solute transport

4 About the Author

John M. (Jack) Sharp, Jr., is the Carlton Professor of Geology Emeritus at The University of Texas (UT). He earned a B. Geological Engineering from the University of Minnesota and a MS and PhD from the University of Illinois. He is a Fellow of the Geological Society of America and the Alexander von Humboldt-Stiftung. He has held positions with the National Science Foundation, the US Geological Survey, the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia as well as Flinders University of South Australia. Jack has been president of the Geological Society of America (GSA) and the Austin Geological Society; treasurer of the International Association of Hydrogeologists (IAH) and Council of Scientific Society Presidents; chair of the US IAH Chapter; and vice-president of the American Institute of Hydrology (AIH). He has edited *Engineering and Environmental Geoscience*, *GSA Bulletin*, *Hydrological Science and Technology*, and *Hydrogeology Journal*, as well as GSA and IAH monographs. Honors include the Meinzer and Hydrogeology Division Distinguished Service awards (GSA), the Theis and Founders awards (AIH), the Presidents' Award (IAH), Lifetime Achievement Award (Barton Springs/Edwards Aquifer Conservation District), 2021 Alumni Achievement Award (University of Illinois), Phi Kappa Phi, and Tau Beta Pi. Jack also held distinguished lectureships at the Edwards Aquifer Authority, as Farvolden Lecturer (University of Waterloo), and as Hoeing Lecturer (Kentucky Geological Survey). He has supervised over 50 undergraduate and precisely 100 graduate theses. He is a registered geologist in the State of Texas and certified as a professional hydrogeologist by the AIH. His hobbies include gardening, genealogy, fishing, duck hunting, Australia, opera, UT football, and (before bad knees) handball.

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Modifications to Original Release

Changes from the Original Version to Version 2

Original Version: October 2, 2023, Version 2: June 19, 2024

Page numbers refer to the original PDF.

Specific changes:

page ii, added version number and date

page iii, added donation page

page iv, updated number of pages

page x, added to acknowledgments

page 1, added second sentence to definition of Acre-Foot

page 1, moved definition of Acoustic Probe down the page to its proper alphabetical order

page 2, added "particulate and colloidal matter" to definition of Advection

page 2, removed first occurrence of Aerosol which was out of order and a duplicate

page 3, added definition of Alkali Flat

page 4, added definition of Alluvial (Adobe) Flat

page 7, changed "commonly" to "has been"

page 7, added definition of Alluvial Aquifer

page 7, extended definition of Exempted Aquifer starting with "for use in"

page 7, added definitions of Major and Minor Aquifer

page 7, enhanced definition of Perched Aquifer

page 7, added definition of Principal Aquifer

page 7, added definition of Semi-perched Aquifer

page 8, added definition of Aquifer Vulnerability

page 13, added definition of Background Concentration

page 13, added definition of Bajada

page 13, added that baseflow may be spelled base flow

page 14, added definition of Closed Basin

page 16, added definition of Biome

page 16, added definition of Black's Law to be in proper alphabetical position

page 17, added definition of Bolson

page 18, removed definition of Black's Law to proper alphabetical position

page 26, added definition of Chelation

page 26, added definition of Clausius - Clapeyron Equation

page 27, added definition of Coarse-Grained

page 28, added definition of Colluvium

page 29, added definition of Common Assessment Level

page 32, added definition of Composite Confining System

page 32, added definition of Conglomerate

page 37, added definition of Coquina

page 37, added definition of Critical Point of Water

page 38, added definition of Cryosphere

page 38, added definition of Crystalline Rocks

page 41, added definition of Debris Flow (Mudflow)

page 41, added definition of Deflation

page 41, added definition of Deformation

page 41, added definition of Degradate

page 42, added definition of Denitrification

page 47, enhanced definition of Dolostone

page 47, added definition of DRASTIC

page 49, added definition of Dune

page 49, added definition of Dust

page 52, added definition of Ecotone

page 52, added definition of Efflorescence

page 53, added definition of Eluant

page 53, added definition of Elutant

page 53, added definition of Eluvial Horizon

page 53, added definition of Eluviation

page 53, enhanced definition of Energy

page 54, added definition of Environmental Geology

page 54, added definition of Eolian

page 54, deleted Equipotential definitions and moved them to proper order

page 54, inserted Equipotential definitions here to be in proper order

page 55, added definition of Eutrophication

page 58, added definition of Listric (growth) Fault

page 58, added definition of Fault Scarp

page 58, added definition of Fault Trace

page 59, added definition of Fine-Grained

page 62, added definition of Fluffy Surface

page 62, added definition of Footslope

page 64, added definition of Fracture Anisotropy Factor

page 64, added definition of Fumigant

page 66, added definition of Geography

page 66, added definition of Geogenic

page 66, added definition of Geogenic Constituents

page 68, added definition of Glairin

page 70, added definition of Groundwater Age

page 70, added definition of Groundwater Residence Time

page 71, added definition of Gypsite

page 71, added definition of Gypsum

page 72, added definition of Halite

page 74, deleted definition of HBSL (Health Based Screening Levels) to move to proper order

page 75, added definition of HBSL (Health Based Screening Levels) in proper order

page 75, added definition of Helium

page 76, added definition of Heuristic

page 77, added definition of HSPF (hydrologic simulation program-FORTRAN)

page 81, added definition of Hydrostatic Level

page 81, extended definition of Hydrostratigraphic Unit

page 81, added definition of Hydrovolcanic

page 82, changed cool to cooler for Hypolimnion

page 83, added definition of Induced Infiltration

page 85, added definition of Integrated Water Resource Management (IWRM)

page 85, changed “the movement” to “transfers” in the definition of Interbasin Transfer

page 87, added definition of Isopach

page 92, added definition of Karst Basin

page 94, added definition of Laguna

page 94, added definition of Land-Use Study

page 94, enhanced definition of Limestone to include “(more than 50%)”

page 96, clarified definition of Lineation

page 97, added definition of LOESS (locally estimated scatterplot smoothing)

page 99, added second occurrence of “that” to the definition of Magmatic Water

page 99, added definition of Manometer

page 101, added definition of Medium-Grained

page 101, added definition of Methemoglobinemia

page 102, added definition of Mirabilites

page 102, enhanced general definition of Model

page 103, added definition of Deterministic Model

page 105, added definition of Mudstone

page 106, added definition of Natural Attenuation

page 110, added definition of Organic Carbon

page 110, added definition of Ostrom Principles

page 113, added definition of Pelecypod

page 114, added “continuously” to definition of Perennial Stream (or Spring)

page 116, added definition of Phreatic Water

page 116, added definition of Phreatomagmatic (Hydrovolcanic) Eruption

page 117, added a sentence to the definition of Piezometer

page 117, enhanced definition of Playa

page 120, enhanced definition of Ponor

page 121, spelled out “greater than zero” for definition of Porous

page 122, added definition of Bulk Precipitation

page 122, added definition of Predevelopment

page 128, enhanced definition of Recharge

page 128, added definition of Artificial Recharge

page 128, placed last line of Recurrence Interval definition next to glossary word

page 129, added definition of Reef Flat Plate

page 132, enhanced definition of Roily

page 135, enhanced definition of Saliferous

page 135, changed definition of Saline Water to read “is used in some state agency publications” rather than “is in some state agency files.”

page 138, added second sentence to definition of Sand

page 142, enhanced definition of Shale

page 142, added definition of SI units

page 142, added definition of Siliciclastic Rocks

page 144, enhanced definition of Solute

page 145, added definition of Solvent

page 148, added definition of Sorting

page 149, enhanced definition of Springshed

page 152, enhanced definition of Ephemeral Stream

page 155, enhanced definition of Supercritical Fluid

page 160, enhanced definition of Thalweg

page 161, added definition of Thenardite

page 161, added definition of Third-party impacts

page 162, added definition of Threshold Effect Level

page 165, added definition of Facilitated Transport

page 165, revised definition of Triple Point

page 165, added definition of Tritium

page 165, added "entire" to definition of Troglobites

page 166, added definition of Tuff

page 167, added definition of Underflow Conduit

page 169, added definition of Valley Fill

page 172, added definition of Vertisols

page 172, replace last sentence before numbered list in the definition of Viscosity

page 172, added definition of Volatile Organic Compound (VOC)

page 172, added definition of Voxel

page 175, added definition of Water Gap

page 177, added definition of Domestic Well

page 177, added definition of Public-Supply Well

page 185, added Aller and others (1987)

page 185, added Boulding (1994)

page 185, added Cleveland and Devlin (1988)

page 185, added reference to Erickson and others (2024)

page 186, added Hawley (2023)

page 187, corrected indent for Stanger, G. (1994).

page 188, added reference to Van Stempvroot and others (1993)

page 189, corrected AFT to AET

page 189, added AoR

page 189, added AVI

page 190, added FEFLOW

page 191, added HSPF

page 191, added IWRM

page 191, added LOESS

page 192, added MODFLOW

page 192, added MT3D

page 192, reworded the description of p

page 193, extended the description of σ

page 194, added ZOT

page 195, enhanced description of the author