INTERPRETIVE GLOSSARY of WATER-RELATED TERMS and EXPRESSIONS

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Last edited 01-25-2017

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abnormal pore pressure: Any pore pressure that differs from **normal pore pressure.** It may be higher than normal or lower than normal. Higher than normal pore pressure sometimes is called *supernormal* pressure, and lower pressure sometimes is called *subnormal* pressure. How subnormal pore pressures can be created in aquifers, refer to **bulk modulus(3).** Higher than normal pore pressure is quite common in aquifers. Also, it can be found in true reservoirs, **lenses** and stratigraphic **traps** that are surrounded by impermeable barriers that prevent communication and relief for the reservoir fluid and its pressure. **Overpressure** can result from a number of different conditions.

(1)Relative to aquifers, the abnormal pressure is called **artesian head.** This is a form of overpressure. It is represented in **Darcy's equation** by the term Δp. Here, the difference in water pressure is due to the difference in the elevations between the **water table** directly under the **outcrop** of the aquifer and the elevation at the depth where water emerges from the aquifer. These two elevations, of water table at the outcrop and elevation of water egress from the aquifer, can be and probably are separated by a comparatively great distance Δd. That distance Δd is seen within the fraction on the right side of the Darcy equation. It can be seen that as distance from the outcrop increases, the flow rate q decreases, and it continues to decrease with a decreasing Δp over distance until the abnormal pressure ultimately dissipates.

The water pressure in unproduced **confined aquifers** usually is greater than normal and the excess is called artesian pressure. In turn, artesian pressure suggests a water table higher in elevation directly above the producing aquifer. This is an imaginary water table and invokes another term. This term is the **potentiometric surface**, defined by O. E. Meinzer, 1923. The water table directly under the outcrop of the aquifer is a real and true potentiometric surface. The potentiometric surface at the water table is projected at decreasing elevations over distance Δd throughout the aquifer. See **artesian head**, **potentiometic surface**, and **Darcy's equation.**

(2)In other granular sediments as well as aquifers, the most common type of overpressure is caused by overburden. **Overburden** is supported by both the grain-to-grain framework of rock and the formation pressure within its pores. See **compaction(2)**. When clay materials are deposited, the associated water (see **connate water**) constitutes a large part of the total volume. While undergoing compaction under the stress of overburden, some of this water is squeezed out of the clay into permeable beds or strata where the expelled water finds **relief**. The water-filled pore volume remaining in the clay shale is directly related to the stress of overburden to a very high degree and as the burial process continues, the water pressure in the pores increases linearly with the **hydrostatic load**. A **normal pore pressure gradient** is established and normal pressure is exhibited. Within this depositional sequence, which can be thousands of feet thick, if there exists a formation or series of beds that have no lateral communicable relief (see **lens**), then the water in the pores of the **clay shales** cannot be expelled, attendant porosity will be preserved, and the formation pressure will increase above normal. The formation pressure will continue to increase as overburden and the stress it produces continues to increase. The increased pore pressure relieves some of the load on the surrounding clay shales and grain-to-grain framework of aquifers, and reduces the rate of **compaction** and compression of pore space. Higher than normal pore pressure in formations can be recognized on **petrophysical logs** where the porosity of associated clay shales is higher than the normal. Overpressured beds are observed in shallow wells as well as extremely deep wells. See **compaction(1)** and **(2)**,and **normal pore pressure**.

absolute permeability: See **permeability(1)**.

absolute water right: A water right, with a specific priority date, that has been placed to beneficial use. **CSU.**

acre-foot: A measurement of a volume of water (43,560 cubic feet, 325,872 gallons) to cover one acre of land one foot deep.

acid: Any chemical compound, one element of which is hydrogen, that dissociates in solution to produce free hydrogen **ions.** For example, hydrochloric acid, HCl, dissociates in water to produce hydrogen ions, H^+, and chloride ions, Cl^-. **SPWLA.** See also **dissociation.**

acid stimulation, acid treatment: This is a radical procedure in water wells and aquifers. The acid compound used in these operations must dissociate in solution to release free hydrogen ions so that the solution will attack and dissolve acid-soluble materials that can restrict the flow of fluids. For well treatments, the acid usually is hydrochloric or a mixture of hydrochloric and hydroflouric acids, or other organic acids. When and if the acid treatment is successful, the acid must be back-flushed by producing water from the well and the pH must be increased to acceptable levels for potable or domestic water. Acid treatments can be designed to stimulate well production, or injection, where the well performance has been affected by any of the following conditions:

(1) Inside the casing. Scale and other precipitates can obstruct and restrict fluid flow in and on downhole equipment.

(2) ln the casing. Slots or perforations in the casing can become encrusted with scale and other deposits that obstruct and restrict the flow of fluids passing from outside to the inside of the casing.

(3) In the well bore environment. During the drilling process, the hydraulic pressure of the drilling mud exceeds the pore pressure within the aquifer. The spurt loss from the drilling mud, and mud filtrate, will invade the aquifer to a specific radial distance depending on the water loss of the drilling mud and the permeability of the aquifer. The filtrate, and particularly the spurt loss, penetrating the pores produces fluid movement and shear inside the pores, and sometimes forces mud solids into the pores. The shear can weaken and break off fragile filaments from clay crystals that can brushpile at pore throats, and the mud solids can plug pores and pore throats, with the result that water flow in or out of the formation can be drastically reduced.

(4) In injection wells. The injected water must be free of solid matter and should be free of bacteria, and the injection rate must not be too high. Foreign matter injected into the aquifer can either cause clay solids to loosen from the pore walls, or hydraulic fluid flow can cause sufficient force to break off fragile filaments of clay crystals. The partially dissolved and broken filaments

can brushpile in pores and pore throats, and any sludge produced by growing bacteria or algae can cause blockage thus reducing the flow rate of produced water. The injected water must be free of contaminants, both inorganic and organic, and the injection rate must begin slowly, and gradually be increased to the economical injection rate.

(5) In the well bore. The production of water produces a pressure gradient toward the well bore and this flow of water produces a hydraulic shear within the pores of the aquifer. When the production rate is too high, the force of the flowing water can break off fragile filaments and platelets of clay crystals, and these in turn can brushpile in the pores and pore throats, thus obstructing flow and reducing the water production rate. Where these clay crystals are found, the number of perforations in the casing must be increased and/or the length of the perforated interval must be increased, thus reducing the flow rate in the near environment of each perforation for the desired production rate at the surface. Sometimes, in order to lengthen the perforation interval so that the number of perforations can be increased, a slant hole is drilled, or the hole is drilled directionally, so that the drilled hole will not be perpendicular to the water-bearing bed, but will penetrate at an angle with the bedding plane so that a longer length of perforated casing remains inside the aquifer. This will allow a greater number of slots or perforations, and reduce the flow rate at each perforation for the same production rate at the surface. Wells where this can be a problem must begin production very slowly with a gradually increasing production rate, thus producing the crystal fragments with the water before they have gathered into brush piles. See **brushpile**.

adjudication: A judicial process in which a priority is assigned to an appropriation and a court decree is issued defining the water right. **Douglas Co.**

adverse use: Using decreed water owned by another appropriator. **CSU.**

aeolian: (1) Wind borne. Sedimentary mineral matter transported by and then deposited by wind to form dunes and other wind-blown features to form porous and permeable strata when buried. From *Aeolus*, mythological Greek god of the winds. Although this term is entrenched in literature, some consider the spelling of the term obsolete and are changing the spelling to **eolian.**

(2) In Greek culture. Pertaining to *Aeolis* or its inhabitants or its language.

aerated zone: The earthen zone at or near the ground surface containing water held by **capillarity**, and containing air at **atmospheric pressure.**

aerobic: Typical of microorganisms that thrive in contact with air and absorb oxygen from the air as they feed upon and bring about decomposition of waste organic matter present in water. Compare **anaerobic** and see **biochemical oxygen demand.**

alkaline: (1) Having the properties of a **base.**

(2) Containing **ions** of one or more alkali metals.

(3) Waters containing more than the average amounts of carbonates of sodium, potassium, magnesium, or calcium. **SPWLA.**

allogenic: Detrital accumulations of rock constituents and minerals derived from the degeneration and mechanical erosion or weathering of older formations and redeposited. Compare with **authigenic.**

alluvial: A term that describes a geological formation that consists of gravels, sands and silts that have been transported by rivers and streams and deposited to form porous and permeable strata. The more distant from the water source, or the slower the velocity of the water in the river or stream, the smaller will be the materials that drop out of the water. The Denver Basin consists of a number of alluvial formations. See **depositional environment.**

alluvial plain: A level, gently sloping, or slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a stream that periodically overflows its banks. **GWAC.**

alluvium: Refers to the unconsolidated sediments such as gravels, sands and silts that have been deposited by rivers and streams.

amorphous: Describes rocks and minerals that have no definite or defined crystalline form.

anaerobic: Typical of microorganisms that thrive where there is no contact with air or free oxygen and obtain oxygen from the decomposition of waste organic matter in water. Compare **aerobic** and see **biochemical oxygen demand.**

anhydrite: A common name for the naturally occurring calcium sulfate. Anhydrite is calcium sulfate ($CaSO_4$) existing in the orthorhombic crystalline form. The anhydrite crystal cannot become a gypsum crystal ($CaSO_4(H_2O)_2$), the monoclinic form, in a single hydration step. Anhydrite must first become dissociated in solution before the ions can recrystallize as gypsum. Compare **gypsum.**

anisotropy: The property of rock to exhibit different responses or measurements when stimulated or measured along different axes.

annular space: In a completed water well, it is the space between the casing and the drilled formation wall that is filled with cement during the completion operation. See **completion**, **isolation**, **channeling**, **cement bond**, and **free pipe**.

appropriation: The diversion of a certain portion of the waters of the State and the application of same to a beneficial use (CRS 37-92-103). Under certain conditions, an appropriation may be accomplished by the state without the act of diversion and application to beneficial use. **Douglas Co.**

appropriative rights: See **Appropriation Doctrine.**

Appropriation Doctrine: The system of water law primarily used in the western United States under which: (1) The right to water is acquired by diverting water and applying to a beneficial use; and (2) a right to water use is superior to a right developed later in time. **CSU.**

appropriator: The person or persons who put water to beneficial use. **CSU.**

aquiclude: A layer of soil, sediment, or rock that is incapable of transmitting significant quantities of water under ordinary hydraulic **pressure gradients.** Often considered to be an impermeable layer or bed that *precludes* the transmission of water. See **pressure gradient** and compare **aquitard.**

aquifer: An underground formation, bed, or stratum of earth, gravel, sand, or other porous rock that contains no liquid other than water, and can transmit mobile water under a sufficient hydraulic **pressure gradient.** There are a number of different kinds of aquifers, three of which are:

(1) **unconfined aquifer.** An aquifer in which the water table serves as the upper surface of the water-saturated zone and the aquifer underlies and has direct contact with the **aerated zone.** This definition would apply to aquifers containing tributary ground water. See **water table, drainage (1)**, and **tributary ground water.**

(2) **confined aquifer.** Usually considered to be an aquifer sandwiched between two impermeable rock layers or strata (or **aquicludes**) at the depth of interest and at the local geographic location. The barriers can be impermeable side beds or any other form of permeability barrier. Might or might not be confined at a remote location, depending on whether or not the water it contains is **renewable.** This is an aquifer that is confined by impermeable barriers and usually is not considered to have communication with atmospheric pressure except at the distant location where water **renewal** can take place, such as an **aquifer recharge area.**

(3) Some **confined aquifers** are surrounded completely by impervious beds and do not contain renewable water. These are aquifers that contain water related to the water that was deposited simultaneously with the **sediments** (see **connate water**). If the aquifer pinches out in all directions and is *completely* surrounded by impervious strata, then the quantity of water is finite and *not* renewable. Some aquifers such as these might exhibit higher than normal pore pressure (see **abnormal pore pressure**), but all will cease water production when the formation pressure or **pore pressure** dissipates or is reduced to the level that the **pressure gradient** toward the well bore becomes insufficient to sustain production. Also see **lens.**

All aquifers containing non-tributary ground water are confined aquifers by the usual definition, but confined aquifers in the same system can be **hydraulically connected.** See **non-tributary ground water** and compare **tributary ground water**.

To help understand aquifers, see **drainage**, **drive mechanism**, **pressure gradient**, and **movable water.** Also see **pass-through aquifer.**

aquifer recharge area: (1) The cross-section of the permeable outcrop or exposed ground-level part of the aquifer. The outcrop representing the recharge area might or might not have the characteristics or properties of the buried aquifer. See **renewal** and **recharge.**

(2) For renewal of non-tributary water. The location where renewal or natural recharge of a **confined aquifer** can take place. Usually an outcrop at elevation, where natural recharge can occur by precipitation from the atmosphere; or at depressions where natural recharge of the aquifer can occur from lakes, rivers, streams, or other water concentrations such as runoff.

The flow from a recharge area is from the highest elevation to the lowest elevation. And the water table that underlies the recharge area or outcrop is a potentiometric surface. See detailed discussions under **potentiometric surface** and **hydraulic conductivity.**

(3) For renewal of tributary water. The area can be a river, stream, lake, basin, or other depression that can allow water to recharge an **unconfined aquifer.**

aquifer test: A test involving the withdrawal of measured quantities of water from, or addition of water to, a well or wells and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition. **GWAC.** This is one of a number of different tests that can be made in production wells and **monitoring wells** for gathering information relative to aquifers. See also **biochemical oxygen demand**, **water analysis**, **pH**, and **potentiometric surface.**

aquifer yield: The maximum rate of withdrawal that can be sustained by an aquifer. Also see **yield.**

aquitard: A body of rock or sediment that *retards* but does not prevent the flow of water to or from an adjacent aquifer. It does not readily yield water to wells or springs but might serve as a storage unit for ground water. **NSSH.**

Arapahoe aquifer: The Arapahoe formation consists of aquifers that underlie the Denver formation, and is composed primarily of sandstone interlayered with shale.

arch: In unconsolidated sand, sand production can occur with the consequence that the casing can be filled with sand to the level of the perforations. This can reduce water production as each slot or perforation becomes covered. In such formations, if production is brought on very slowly an arch can form on the outside of the casing over each perforation when the sand grains wedge together. Each arch has the chance to remain as long as the production rate is low.

argillaceous: Formations, beds, and strata that contain significant proportions of clay minerals such as found in shales, silts, and slate.

artesian head: The **hydrostatic head** of water in the well bore of a static, **shut in**, or non producing well such as a **monitoring well**. See **hydrostatic head (2)**, **back pressure**, and **potentiometric surface.** Also see **abnormal pore pressure (1)**.

artesian pressure: Pressure exhibited by the artesian head. See **artesian head.**

artesian water: Water from an aquifer, below any form of **aquiclude**, that has enough hydraulic pressure to force the water level in the well bore to rise above the depth of the aquifer. The water level might or might not rise to the surface of the ground. See **hydraulic pressure** and **back pressure**, **artesian head**, also **aquiclude.**

artificial: Unnatural. Manmade. Manufactured.

artificial recharge: A method by which water which has been put to prior beneficial use is injected into or <u>returned</u> to aquifers for purposes of <u>replacing</u> water that has been removed.

atmospheric pressure: The pressure of the atmosphere at the surface of the earth, dependent on elevation. At sea level, the pressure is approximately 14.7 psi.

augmentation: An artificial means to add to any groundwater supply or energy downstream from its origin.

augmentation plan: A plan to replace depletions from water pumped from a non-exempt well. Also, a court-approved plan that allows a junior water user to divert water out of priority so long as adequate replacement is made to the affected stream system preventing injury to the water rights of senior users. **CSU**. Also see **non-exempt well.**

authigenic: Constituents within the interstices of gravel, sand, or rock that formed or were generated by saturated solutions at the location where they are found. Particularly, crystals of minerals that are found adhering to and coating the walls of the pores within a host rock such as sand. Typical authigenic minerals are quartz, carbonates, and clays. In aquifers, the presence of authigenic crystals, particularly those of clay, can cause flow problems in both injection and production wells. See **acid treatment**, **brushpile**, and **formation damage.** Compare with **allogenic.**

back pressure: (1) Under static conditions, the hydrostatic pressure in a borehole or other vertical *conduits*, such as natural fissures or fractures, equal and opposite to the pore pressure in an aquifer, that prevents water from flowing out of the aquifer. Sometimes insufficient in springs and artesian wells to prevent water from flowing to the surface of the ground.

(2) In a water well, back pressure is that positive pressure difference, under producing conditions, between the depth of the surface of the water column inside the well casing and the depth of the producing aquifer. When the level of the water column falls to the depth of the pump, water production will cease. See **coning** and **water level (2)**. Compare **drawdown.**

(3) In a producing well where crossflow production occurs, it is the positive difference in pressure between the depth of the surface of the water column inside the well casing and the depth of the aquifer where crossflow originates. This back pressure can be zero if the dynamic water level is at or below the depth of the aquifer producing the

crossflow. See **thief level**, **thief zone**, also **water level (2)**.

(4) In a drilling well, it is the **hydrostatic pressure** produced by the engineered drilling mud in the borehole, equal to or greater than the pore pressure in a drilled formation, that prevents any geofluid (water, oil, or gas) from flowing out of the formation. In the case of hydrocarbons, if the head of drilling mud does not balance or overbalance the formation pressure the well can discharge with disastrous consequences. See **drilling mud.**

(5) With its designed density, the drilling mud can provide sufficient back pressure to help prevent the collapse of the borehole.

bacteria: One-celled microorganisms. Some forms are beneficial, others are unsafe for human consumption. Coliform bacteria is an example of harmful bacteria.

bail: To bail. In drilled holes, the mud and water remaining in the well bore after drilling the hole and setting the casing must be bailed out of the hole by a long bucket-like container on the end of a cable before the well can be flushed, disinfected, and put on production.

bank storage: Water contained in an aquifer that is in communication with a stream or lake and capable of supplying water to the stream or lake following a lowering of the open water surface; or, of storing water flowing from the stream or lake following a rise of the open water surface. **Douglas Co.**

bar: (1) Of a stream. A general term for a ridge-like accumulation of sand, gravel, or other alluvial material formed in the channel, along the banks, or at the mouth of a stream where a decrease in water velocity allows deposition.

(2) Coastal. A generic term for any of various elongate offshore ridges, banks, or mounds of sand, gravel, or other unconsolidated material submerged at least at high tide, and built up by the action of waves or currents, especially at the mouth of a river or estuary, or at a slight distance offshore from the a beach. **NSSH.**

barrier: Any impermeable bed or strata in contact with an aquifer that prevents the flow of formation water to or from the aquifer. See **cap rock.**

base: Relative to chemistry, it is a substance capable of combining with charged hydrogen atoms (**ions**) to form a salt. A typical base is sodium hydroxide (caustic) with the chemical symbol NaOH. **SPWLA.** Compare **acid.**

base flow: The amount of water in a stream that results from ground water discharge. **CSU.**

basement: The undifferentiated rock that underlies sedimentary rock. Mostly of **igneous** or **metamorphic** nature.

basin: (1) An ancient lake or sea bed or other surface or subsurface synclinal structure where sediment can accumulate or has accumulated to form a porous and permeable rock body.

(2) Drainage basin. The area of land that drains to a specific river or stream.

basin rank: A number used in the State Engineer's tabulations of decreed water rights to indicate the relative seniority of a decreed right as determined by its date of adjudication and the date of appropriation. **Douglas Co.**

basin yield: The maximum rate of withdrawal that can be sustained by the complete hydrogeologic system in a basin without causing unacceptable declines in hydraulic pressure anywhere in the system or causing detriment to any other component of the hydrologic cycle in the basin. **GWAC.** See **yield.**

beach sands: Well-sorted, sand-sized, clastic material transported and deposited primarily by wave action and deposited in a shore environment. Compare **aeolian** or **eolian. NSSH.**

bed: (1) A lithostratigraphic unit of rock. A homogeneous subdivision of a stratified rock sequence within a formation.

(2) The floor or bottom of lake, ocean, sea, river, or stream.

bedded: Formed, arranged, or deposited in layers or beds, or made up of or occurring in the form of beds; especially said of a layered sedimentary rock, deposit, or formation. **NSSH.**

bedrock: Solid, unweathered rock below **unconsolidated** sediments.

beneficial use: The use of water that is reasonable and appropriate under reasonably efficient practices to accomplish, without waste, the purpose for which diversion is lawfully made; and shall include the impoundment of water for recreational purposes, including fishery or wildlife (CRS 37-92-103). **Douglas Co.**

bentonite: Composed of **montmorillonite** formed from the decomposition of volcanic ash, a swelling clay when in contact with water. Because of its property to swell, it is a major component of **drilling mud** for the purpose of minimizing the penetration of mud solids and **mud filtrate** into the formation during the drilling process. Often used to line ditches, carrying irrigation water, and ponds for the purpose of reducing loss by seepage and **percolation.**

Best Management Practices: BMPs. Practices that are technically and economically feasible and for which significant water conservation or water quality benefits can be achieved. **CSU.** See **environmental concerns.**

biochemical oxygen demand, biological oxygen demand: BOD. Microorganisms consume oxygen as they feed upon and bring about the decomposition of organic waste in samples of water that have been subjected to pollution. BOD is one of the better methods to measure the amount of oxygen, dissolved in water, that is consumed by **aerobic** microorganisms. BOD is an indirect measure of the amount of pollution. On a numbered scale in units of ppm or mg/liter, the higher the number, the greater is the amount of oxygen required for decomposition; and, therefore, it is inferred the greater is the amount of pollution. BOD levels in the range of 1-2 are very good, those in the range of 3-5 are moderate, 6-9 are fairly polluted, and greater than 10 are very polluted. See also **water analysis** and **pH.**

biogenic methane: Biogenic methane is created by the decomposition of organic material through fermentation, as is commonly seen in wetlands, or by the chemical reduction of carbon dioxide. It is found in some shallow, water-bearing geologic formations containing coals, into which water wells sometimes are completed.

The COGCC has consistently found that biogenic gas contains only **methane** and a very small amount of ethane, while thermogenic gas contains not just methane and ethane but also heavier hydrocarbons such as propane, butane, pentane, and hexanes. **COGCC.** See **thermogenic methane** and **flaming water.**

bond: (1) The state of adherence or joining of one material to another.

(2) In water well completions, the degree of bond can describe the quality of adherence of cement to casing and/or the quality of adherence of cement to the drilled formation wall. See **cement bond.**

borehole: The cylindrical hole that is drilled into and through earthen formations by a drilling rig. The powered drilling rig rotates a drill bit at the end of a string of drill pipe. See **drill pipe.**

brackish water: Of intermediate salinity. Saltier than potable water, but not as salty as sea water. Usually considered to have a salinity of from 1,000 to 10,000 ppm of total dissolved solids. See **total dissolved solids.**

breccia: A coarse-grained, clastic rock composed of angular rock fragments commonly bonded by a mineral cement in a finer-grained matrix of varying composition and origin. The consolidated equivalent of rubble. **NSSH.**

bridge: (1) Constriction in a drilled hole sometimes caused by swelling clays or plastic shales. See **plastic shale.**

(2) The plugging, inside the slots or perforations, by cementing materials or sand grains.

brine: A highly saline solution of salt and water.

brushpile, brushpiling: Clay crystals with fragile filaments or platelets sometimes can be weakened or broken by disturbances to the equilibrium and dynamics of their environment. Such disturbances can be brought about by an increase in injection water temperature, change in pressure, change in salinity of injected water, or flow rate of water over and past the crystals. These disturbances can cause swelling, weakening, or shearing of the fragile crystals that are then pushed into smaller pores and pore throats by either the hydraulic pressure required for the injection process or by the formation pressure during the water production process, thus causing brush piles that restrict fluid flow. The propensity to brushpile, and brushpiling, can be inhibited by mitigating the conditions that cause the disturbances, including beginning injection or production slowly and reducing the injection rate or production rate. By starting the injection or production process slowly, the broken fragments can be moved gently out of the pores and through the pore throats without brushpiling.

buildout: Completion of the development or project as it was approved. **Douglas Co.**

bulk modulus: For water. (1) For most practical purposes, water is incompressible. The bulk modulus of elasticity describing the pressure/strain relationship for water is the reciprocal of the compressibility of water. As the reciprocal of compressibility, it will be recognized that, as the bulk modulus increases, compressibility decreases. The higher the bulk modulus for any material, the more incompressible that material becomes. However, because the bulk modulus for water has a finite value, the waters in the aquifers of the **Denver Basin** can expand as water usage decreases pore pressure. In the Denver Basin where the total amount of ground water is said to be 467,000,000 acre feet, the expansion does constitute some volume, albeit relatively insignificant. In a simplified calculation, for illustration purposes only, the bulk modulus is represented by

$$E = (-)(\text{change in pressure})/(\text{relative deformation}) = (-)\Delta p/((\Delta v)/v_o)$$

where E = bulk modulus for water = 3.12×10^5
Δp = pressure change (lb/in^2), for this illustration, minus 10 psi
Δv = change in water volume (acre feet)
v_o = original water volume = 467×10^6 acre feet

Assuming the total amount of water in the Denver Basin is

467 x 10^6 acre feet and 100% of the water (or any fraction thereof) is subject to a minus 10 lb/in^2 change in pore pressure due to water production, then for every 10 psi reduction in pore pressure, the change in total volume due to expansion is

Δv = (-)(-10 lb/in^2)(467 x 10^6)/(3.12 x 10^5) = (+)14,968 acre feet, or 14,968 acre feet expansion in water volume for every 10 lb/in^2 decrease in pore pressure.

Water expansion in this illustration, in whatever quantity, contributes to the groundwater supply.

(2) Although minimal in the case of nearly incompressible ground water, expansion is finite and does take place as water is produced from the aquifer and pumped to the ground surface where temperature and pressure change from in situ conditions to surface conditions. This form of expansion upon withdrawal from the well bore also applies to other fluids, such as natural gas and crude oil, where the increase in volume can be very significant.

(3) Differences between the elasticity of rock and water can cause subnormal pressure in aquifers, and water will be imported from a higher pressure environment to a lower pressure environment. Along with increased water production, as the **potentiometric surface** falls, is a decrease in the **hydrostatic head.** This reduction in pressure causes the expansion of water as discussed in (1) above. Not only does the decline in pressure allow water to expand, but it allows rock to expand as well. The bulk moduli of rock and water are different, and this difference allows the relative volumes to expand at different rates.

For the same difference in pressure decline, rock will expand more than water. This is due to **elasticity**. So, as the water pressure declines with excessive water withdrawal, rock will expand and the pore spaces between the grains of the rock will expand to a volume greater than the expanding water. Although the volume of water will increase to fill the expanded pore, its pressure is reduced in order to do so. Water pressure now has been reduced further than from excessive water withdrawal alone. This subnormal water pressure compounds the differential in pressure between the vicinity of the high-volume water-producing well and that in the environment of distant wells. This negative pressure difference is in addition to the pressure decline due to excessive water production at the producing well site. This elastic behavior in rock and water causes additional water to be imported to the site of the producing well.

The elastic properties of both the rock and the water are reversible. This allows limited **rebound.** The elastic behavior of rock and water is different from the effects of compaction as seen in the Rubey & Hubbert relationship in **compaction(2)**. The compaction that takes place as a result of the reduction in pressure is not reversible.

(4) For virtually every action there is a reaction. Along with the reduction in pressure described in (3) immediately above, will be additional compaction by the overburden. See **compaction(2)**. This tendency to re-compress the rock and water in the aquifer tends to offset the tendency for elastic expansion to some degree. How much the elastic expansion will be countered will depend on the thickness and weight of the overburden, hence, the depth of the aquifer. Although somewhat attenuated, the compaction force will overwhelm the expansion force, and **subsidence** will occur at the ground surface.

buoyancy: An upward force tending to counter the downward force of **gravity**. Buoyancy takes place in the presence of liquids and gases, liquids and solids, and immiscible liquids. Buoyancy depends on the difference between the densities of any two materials, one immersed or suspended in the other; and, in rocks, on *which material constitutes the host phase* and provides buoyancy to the other. This consideration is based on Archimedes' Principle where *a body immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced*. In the case of the **aerated zone** containing air and water, the host phase is air at atmospheric pressure and the buoyant force of air is negligible, and the component of water volume supported by buoyancy is insignificant. The full force of **gravity** is now effective on the water volume occupying the voids within the earthen materials and/or adhering to the surfaces of grains and particles of gravel, sand, or rock. Relative to **irreducible water** where the host or mobile phase is oil and the density is much greater than that of air, the buoyancy is greater, and the immobile phase of water becomes greater. Also see **gravity drainage** and other factors related to **irreducible**

water: **capillarity**, **surface tension**, and **evaporation**.

calcite: (1) A mineral, calcium carbonate ($CaCO_3$).

(2) Also limestone. A sedimentary rock consisting primarily of the mineral calcium carbonate.

calcium carbonate: (1) A sedimentary mineral made up of calcium, carbon and oxygen ($CaCO_3$) that was formed from skeletal remains and secretions of organisms precipitated from water.

(2) A major component in hard water and forms a tenacious crust on water-handling equipment.

caliche: A general term for a prominent layer of secondary carbonate accumulation in surficial materials in warm, subhumid to arid areas. **NSSH**.

California Doctrine: A legal doctrine retaining aspects of both riparian rights and principles of prior appropriation. **CSU**.

call: The placing of a call by a senior priority to the water commissioner to stop or diminish junior diversions so that the requested amount of water may be passed to the downstream senior diversion. In such cases, junior priorities are curtailed or "called out".

capillarity: The net imbalance between surface attractions (adhesion) at the interfaces between liquids and solids, and **surface tension** (cohesive force) of liquids. Capillarity provides the net attraction or repulsion for liquids to rise or be depressed in small pores, voids, or interstices. See also **wettability**.

If the liquid is water and the water tends to wet the solid surfaces of soil and rock surrounding fine pores and interstices, then the molecular adhesive attraction between water and rock surfaces tends to be greater than the intermolecular cohesive attraction within the water, and there will be a positive pressure causing the water to penetrate the fine pores of the rock.

In soils and aquifers, where water is attracted to and wets the solid surfaces, the adhesive attractions are the predominant force, and water is retained in fine pores with great tenacity. Water held by capillarity in an aquifer cannot be produced and is part of the **irreducible water.**

capillary fringe: See **aerated zone.**

caprock: (1) The impermeable rock or shale overlying an aquifer that serves as a barrier to prevent water in a permeable aquifer from moving upward in the formation, therefore helping to maintain the pressure in the aquifer.

(2) The hard weather-resistant rock layer composed of sandstone, limestone, or lava that overlies any softer layer of rock.

carbonaceous: Containing carbon or coal derived from buried organic matter.

carbonate: (1) A sedimentary rock containing calcium carbonate (**limestone**) or calcium magnesium carbonate (**dolomite**) precipitated from sea water.

(2) The negatively charged ion cluster or radical CO_3 in a solution containing dissociated ions of a salt such as sodium carbonate (Na_2CO_3). See **ions.**

casing: In water wells it is a steel or PVC pipe that is installed in the borehole to keep the borehole from collapsing and to protect drilled aquifers from contamination. Encloses tubing and pump in completed wells. Also see **conductor pipe**, **surface casing**, **intermediate casing**, **production casing**, **protection casing.**

casinghead: The top of the protective casing at the surface, or first casing string, that has the appropriate means for attaching various fittings and equipment assemblies.

casing point: The depth where the bottom of the casing is to be set.
Generally the bottom of the hole and the casing point are planned to be the same depth.

casing pressure: The pressure in the annulus between the casing and the tubing. Might or might not be at atmospheric pressure.

cement bond: Is related to the quality that cement adheres to either or both the casing and the formation wall. In water well completions, the annular space between the casing and the drilled formation wall is intentionally filled with cement to isolate aquifers and stabilize the casing. The quality of adherence or bonding of the cement with the casing and/or with the formation wall determines the effectiveness of the cementing operation. The bond is defective where the cement bond is weak, or where cement is absent or missing. The void in the annular space then might constitute a channel or might allow a channel to form between aquifers or between aquifers and the level where water production takes place. See **channel** and **channeling**.

cementation: A term not used in relation to the completion process of cementing casing in a well. This term is used to refer to the precipitation from interstitial waters, and the mineral growth of material that binds sand grains or other rock materials together to become a consolidated rock. Typical cementing materials are **authigenic** crystals of quartz and carbonates.

central water system: A central, public, community water system that gathers water to serve a community or subdivision on a year-round basis.

certification: The process whereby a permit to appropriate water is finalized based on the completion of the diversion work and past application of water to the proposed use in accordance with the approved water-right application. A certified water right has a legal, State-issued document that establishes a priority date, type of beneficial use, and the maximum amount of water that can be used annually. **GWAC.**

change of water right: Any change in a way a water right is used. Can be changed in type, place, time of use, point of diversion, adding points of diversion, etc. Changes of water rights must be approved by the water court to assure that no injury occurs to other water rights. **CSU.**

channel: (1) A defect in the cement quality in a water well where the cement, intended for isolation of aquifers, does not fully occupy the annulus between the casing and formation wall. This defect can provide communication and can serve as a conduit for water to crossflow from one aquifer to another with subsequent loss of integrity and pressure; or, in a producing water well, can allow water to crossflow from an unauthorized aquifer to the level where water is admitted to the casing and withdrawn by the pump, thus allowing depletion of the unauthorized aquifer. See **crossflow.**

(2) Of a river bed or stream bed.

(3) A river bed or stream bed that has become buried by overburden and has become a channel, finger, conduit, or other connecting part of an aquifer.

channeling: In water wells, it is water crossflowing behind casing from one depth to another. The water will crossflow from an aquifer at higher water pressure to another at lower pressure, or crossflow from one depth to another where the opposing pressure is lower. See **crossflow.**

charge: To load, to fill, to add to energy or supply. A generic term.
Compare **recharge**.

chlorite: A magnesium, iron, aluminum silicate. Exhibits intermediate to high radioactivity level of the clays. Density 2.76 g/cm^3 Found as authigenic, pore-lining clusters and rosettes of leafy crystals standing on end.

clastic: Sedimentary rock formed from the degradation or disintegration products of preexisting rock which have been moved individually from their place of origin.

clay: A major constituent in most shales. Fine hydrous silicate minerals with several different crystalline forms depending on the mineral. Some with platelets and leaves, some with fibers. Each clay mineral exhibits its own radioactivity level. Compare **shale.**

clay shale: A clay shale is a shale wherein the major mineral constituent is clay. Usually has high porosity of 35 to 45 percent occupied by **connate water**. Compacts readily under stress of **overburden** while expelling a fresher component of water. See **shale** and **compaction.**

clay shale: A clay shale is a shale wherein the major mineral constituent is clay. Usually has high porosity of 35 to 45 percent. Occupied by water closely related to **connate**

water. Compacts readily under stress of **overburden** while a fresher component of water is expelled. See **shale** and **compaction.**

coefficient of storage: See **storativity.**

COGCC: Colorado Oil and Gas Conservation Commission. See also www.colorado.gov/cogcc.

coliform bacteria: A type of bacteria that is found in the intestinal tract of all animals including humans. Levels of these bacteria are used as an indicator of water-well cleanliness. **CSU.**

Colorado Doctrine: The doctrine regulating water usage by priority of appropriation as opposed to riparian rights. See **appropriation doctrine. CSU.**

Colorado Water Quality Control Act: Legislation to prevent injury to beneficial uses made of state waters to maximize the beneficial uses of water and to achieve the maximum practical degree of water quality in Colorado. **GWAC.**

communication: Any condition, action or means that allows water to flow and/or water pressure to be transmitted from one location to another. Sometimes a condition that hydraulically connects two or more aquifers. Sometimes for the purpose of seeking relief. See **relief** and compare **isolation.**

community water system: See **central water system.**

compact: (1)An agreement between states apportioning the water of a river basin to each of the signatory states. **CSU.**

(2) The act of compacting. To compress. See **compaction.**

compact call: The requirement that an upstream state cease or curtail water diversions from the river system that is the subject of the compact so that downstream states' compact entitlements may be met. **CSU.**

compaction: (1) A natural occurrence. It is the normal compaction of the **overburden** and underlying beds that takes place as sedimentation continues and overburden increases in weight. When **sediments** initially are deposited, the water-filled interpore void space is at its greatest. As the sedimentary process continues, the increasing weight of the overburden progressively squeezes water out of all underlying sediments, resulting in a continually decreasing **porosity**. As long as the expelled water can find relief, a **normal pore pressure gradient** will be established and observed. See **abnormal pore pressure** and **normal pore pressure**.

(2) Related to producing aquifers. When the pore pressure of an aquifer is reduced by water production, the framework of the sedimentary materials surrounding the pore space is subjected to an increased proportion of the weight of the overburden. In this event, there is a strong likelihood that compaction will resume as pore pressure diminishes.

In the following relationship, after Rubey, William W. and Hubbert, M. King, *Bull. Geol. Soc. Am.*, Vol. 70,(1959), an equilibrium exists.

Overburden (psi) = grain-to-grain pressure (psi) + **pore pressure** (psi)

In this equality, the stress of overburden (**geostatic load**) is supported by the grain-to-grain stress (**lithostatic load**) + pore pressure (resulting from **hydrostatic load**), all expressed in units of pressure. In this balance, depressurization in the pore space continues as long as water production continues; pore pressure is reduced and the proportion of the geostatic load supported by the structural framework of the clay shales and aquifers increases correspondingly to maintain the equality. The increase in the compactive force borne by the rock framework might or might not be sufficient to support the overburden. If not, grains and particles of shales, sands, and other minerals will undergo further readjustment, deformation, distortion, and compression. If this happens, additional water will be expelled from the **clay shales**, total pore volume will be reduced by the additional compaction within the clay shales and aquifers. Because nearly incompressible formation water actually expands as pore pressure diminishes (see **bulk modulus**), the compaction of the structural framework, particularly of the clay shales, is accompanied by the expulsion of water, and the compaction process will continue all the while maintaining the state of equilibrium in the equality above. It is possible that some measure of **subsidence** of the ground surface will occur. See also **drainage(2)**and **bulk modulus(3) and (4)**.

Shales and clay shales have the most serious role in the compaction process and resulting subsidence. For the most part, clay shales and the aquifers they surround have been subjected to the stress of overburden over the span of geologic time from the time of deposition to the present. By far the greatest compaction the shales will undergo, for this depth and geostatic load, has already taken place. Further compaction, and therefore recognizable subsidence, cannot take place unless additional dewatering takes place. And, this additional dewatering cannot take place unless water pressure is further decreased by additional water production from the aquifers.

In the clay shales overlying **unconfined aquifers**, from the ground surface to the depth of the **water table** there will be no further compaction resulting from any behavior within the underlying aquifers. Below the water table, in **confined aquifers**, changes in water pressure in the aquifer and in the adjoining clay shales can be affected by excessive water production. As water production continues, water pressure within the aquifers decreases. All waters in communication with the waters in the producing aquifers will be subject to the same decompression, and the framework materials surrounding the pore spaces will undergo increased compactive stress, in conformance with the pressure balance shown above. The structural framework supporting the clay shales will resume compaction and there might be alteration of the pore space within the aquifers, as well. Additional water is squeezed from the compacting clay shales, and, pore space in the clay shales and aquifers decreases in total volume. The events found on the right side of the equilibrium balance equation above are not sequential, but occur simultaneously while obeying the fundamentals of equilibrium. <u>The resulting effect of this behavior is an addition to aquifer water supply by water expelled from the surrounding shales</u>, and an artificial maintenance of pressure within the aquifers. This artificial decrease in the pressure decline rate could be misleading and erroneously could be attributed to natural **recharge**. If subsidence of the overlying ground surface is measurable, then only part of the pressure maintenance is due to **natural recharge**. Also see **rebound**.

In compliance with **Pascal's Law**, all communicating waters experience the same changes in pressure. The clay shales underlying aquifers experience loss of water as do those above, but with moderation. As the clay shales associated with the aquifer system continue to be dewatered by the production of water from permeable aquifers, the geostatic load due to overburden continually decreases by the loss of water, thus expelling slightly less water from underlying shales. What water is expelled must move upward against gravity to find relief. This results in a small decrease in the rate that underlying shales compact.

Compaction cannot take place indefinitely. It is limited by the amount of **overburden** and the amount of **hydrostatic load**, both of which progressively increase with depth. Ultimately, but not necessarily during the span of the wells beneficial life, if pressure decline were to continue, compaction will respond less and less to the production of water as the framework gains rigidity commensurate with the lithostatic load it supports. After all compaction has taken place that will take place, for that depth of interest and that degree of compaction only, the pressure in the remaining water will decline rapidly due to the imbalance between **withdrawal** and **recharge** that caused the decline in pore pressure in the first place.

This behavior of producing aquifers and associated clay shales is predicated on the occurrence of measurable subsidence occurring at the ground surface.

completion, completion practice: There are at least three parts to the mechanics of water well completions:

(1) Running PVC or steel casing from the ground surface to the bottom of the drilled hole to prevent the collapse or caving of the borehole.

(2) Providing a means for water to enter the casing from outside the casing. This usually is provided by slots in the casing or by **gun** perforations.

(3) Cementing or grouting the casing in place with a cement or cement-bentonite mixture to ensure that all aquifers are effectively isolated so that crossflow or contamination cannot take place. Steps (2) and (3) can be performed in

reverse order depending on the means used for putting entry holes in the casing. See **crossflow**, also **thief level**, and **thief zone.**

(4) A 4th part of the process is that well logs should be run in the borehole under openhole conditions, before the casing string is run in the hole, in order to evaluate the formations and strata containing the aquifers. And, well logs should be run again after the casing has been cemented in place in order to evaluate the quality of the completion work. Remedial work can be performed if necessary. See **surface casing**, **well log**, **well logging**, **gun perforating** and **squeeze cementing.**

(5) A final part of the preparation of a well for operation would be installation of the pump and disinfection of all downhole hardware. See **disinfectant.**

(6) Although there can be natural communication between permeable beds, such as by fractures, it is important to note the possible consequences in water wells when the completion of oil or gas wells is faulty. In oil and gas wells, if both the **surface casing** and the **production casing** are not completed properly, oil or gas under pressure from producing wells, or from **shut-in** wells, or from capped uneconomical wells, or from plugged and abandoned wells, can enter **channels** in the **annular space** between the production casing and the face of the drilled hole. In oil and gas wells, if **hydraulic fracturing** is employed to increase the permeability of the hydrocarbon-bearing zone and to improve the production rate, the high pressure necessary to produce fractures can break down the cement sheath in the annular space between the production casing and drilled formation wall. If this happens, it creates a path for the oil or gas to communicate with beds at shallower depths. If the **formation pressure** in the oil- or gas-bearing strata is great enough it can force oil, gas, or salt water, to rise to the depth of the permeable aquifers where it can communicate with and contaminate any or all unprotected aquifers.

Once a contaminating fluid has found a path to shallower depths it will seek relief to any region exhibiting a lower pressure. If no relief can be found at the **wellhead**, the contaminant, whether it is salt water or oil or natural gas, will seek relief in permeable aquifers where it can migrate laterally until relief is found, or until pressure equalizes. **Darcy's equation** applies. In the case of a gas well where free gas is produced, or an oil well where the oil has a high gas-to-oil ratio, gas dissolved in the oil can come out of solution when the oil enters the lower-pressured environment of the well bore, and all free gas then can rise to the level of the aquifers, and the formation pressure in the hydrocarbon-bearing beds will be transmitted to the aquifers with <u>little change in pressure</u> because of the low **density** of the gas.

This gas, under pressure from the oil- and/or gas-bearing formation, will seek relief in permeable aquifers if it cannot find an alternate path to the atmosphere. In response to the excessive pressure, the two separate volumes of water and gas tend to combine into a smaller volume in order to relieve some of the pressure. To do this, gas goes into solution. Without excessive pressure, gas and water will remain separated. This gas, both dissolved and undissolved, which has been forced to migrate within an aquifer will come out of solution, or separate from water, when the water is exposed to the prevailing **atmospheric pressure**. This gas is flammable.

This is a common occurrence when water wells are located amid or near the deeper oil and gas wells, and when completions in either water wells or in oil and gas wells are faulty, or when the completion has become deteriorated or near failure, or because the hydraulic fracturing pressure has broken down the cement sheath. Isolation of the aquifers then fails. Although it is possible for gas to dissolve in ground water under natural conditions, there must be a means of communication between the source and the aquifer, and the pressure within the aquifer must be increased to cause the gas to dissolve in the ground water.

In water wells drilled through beds containing coals, sulfur contaminants and biogenic methane are common. Such constituents found in association with coals can find their way into domestic water supplies if the aquifers or the beds containing coals are not effectively isolated, or if isolation is broken down. Any communication between the aquifer of interest and coals can result in contamination of the water supply by sulfur or biogenic gas. Communication from one bed to another can be caused by faulty completion of the well or when the completion degrades or breaks down under increased pressure in the **annular space**, or if any form of natural fracture system has created a communicable path between aquifers and contamination source.

The source of contamination and the path the contaminant takes can be determined from appropriate **well logs.** See **well log (2)** in particular. The nature of the flammable gas, i.e. biogenic or thermogenic, can be determined by laboratory methods, and thus the source can be identified. Remedial work involving **well logging**, **gun perforating**, and **squeeze cementing** might be necessary. See more under **flaming water.** Also see **methane**, **biogenic methane**, and **thermogenic methane.**

compressibility: Of water. See under **bulk modulus.**

conditional water right: The legal reservation of a senior priority water right which becomes an absolute right when, with reasonable diligence, the water user develops the right and water is actually put to beneficial use. (CRS 37-92-103).

conductor pipe: A short length of large-diameter **casing** used to keep the well bore open, and to provide a means to direct the **drilling mud**, returning from the drill hole, into the **mud pit** from which the mud can be recirculated. **SPWLA.** Compare **surface casing..**

conduit: (1) A means through which water can flow from one location to another. Open ended, unending, or continuous porous and permeable aquifers serve as a means for water to flow from its source of charge and renewal to the location of withdrawal. Also see **pass-through aquifer.**

(2) A means that facilitates flow from one location at one pressure to another at lower pressure. Compare **reservoir,** also see **channel** and **channeling.**

(3) Natural communicable breaks such as fissures and fractures in consolidated or brittle rock.

cone, **cone of depression:** In aquifers, the sometimes undesirable, inverted, cone-like distortion in the air-water interface where air from an overlying **aerated zone**, or air from the well bore or casing annulus, is drawn downward within the near environment of the well bore. Often appears in wells with high production rates where **drawdown** is large. See **coning** for expanded explanation.

cone of depression: See **cone** and **coning.**

confined aquifer: See **aquifer (2).**

confining bed: One or more of the impermeable side beds that prevent the movement of water outside of the water stream of an aquifer. See **aquiclude** and **aquifer (2).**

conglomerate: A course-grained sediment mixture composed of rounded waterworn fragments of rock, cobbles, pebbles, and grains generally bound together by finer-sized cementing minerals. See **consolidation** and **cementation.**

coning: In a producing water well. There are two forms of cone that can occur in the near environment of producing water wells. One is a naturally occurring cone of depression (see 1 below)in an **unconfined aquifer** when air from the **aerated zone** replaces produced water. The other is an unnatural occurrence (see 2 below) caused by improper production and completion practices.

(**1) Cone of depression.** A depression in the plane of the **water table.** It is based on the premise that the production of water from an aquifer cannot take place unless the void left by produced water is re-occupied. The cone occurs particularly in **unconfined aquifers** where water is produced by **gravity drainage.** Air from the aerated zone replaces water that has drained from the near environment of the well bore. The radial effects of the drainage and re-occupation begin at the borehole at the contact of the **water table** and the **aerated zone**, and grow from top to bottom with time. The effects are greatest near the borehole and diminish as radial distance increases from the borehole, producing the appearance of a relatively flat cone-like depressed zone that has undergone the process of being drained of free water. The result is: The **hydraulic head** within the aquifer decreases near the well bore where the depression is the greatest and increases with radial distance from the borehole.

The size of the cone of depression is a function of the **absolute permeability** to water in the producing part of an aquifer, height or distance from the pump depth to the aerated zone, and the rate of water production, as well as time. As the cone of depression grows and becomes large relative to aquifer thickness, the unaffected producing area immediately below the cone decreases in size and the hydraulic head at that point in the aquifer decreases correspondingly, causing the production rate to decrease. If the **drawdown** is increased to compensate for the natural decrease in production, then the second form of cone (under (2) below) might occur.

(2) Coning as a form of aquifer damage and/or well damage. Production of water produces **pressure gradients** in all directions from the depth of pump access. For a cone to form in a confined aquifer requires a source of air and communication with the air. When the gradient to the air-water interface, wherever it might be, becomes smaller than the gradient required to drive water to the well bore, air will be drawn downward toward the depth of access to the pump, thus producing a cone. If the air reaches the pump, water production will cease.

In practice, this form of coning is caused by the excessive water production rate at the pump relative to the producing thickness of the aquifer and its **absolute permeability** to water. This causes excessive **drawdown** that can cause the gradient to air to be smaller than the gradient driving water to the borehole. Thus, coning begins. As the excessive drawdown further depresses the cone, the gradient to air further decreases. The air-water interface between the cone and the water is a depression in the **potentiometric surface**. Water production will continue as long as the potentiometric surface is above the pump, and as long as there is pressure to drive the water out of the rock. The cone might reach equilibrium with the production rate and stabilize, or the cone might continue to grow until air reaches the pump, at which time water production will become sporadic and cease.

To reduce the likelihood of producing a cone, the production rate must be decreased. Once coning has occurred it might be difficult to reverse the damage to the aquifer because air has been introduced where it did not exist before, and the **effective permeability** to water within the volume of the cone might be permanently decreased. See **permeability**.

The thickness of the aquifer of interest, and the number of **beds** and **laminae** and their thicknesses opened to production, will influence the size and shape of the cone in both cases (1) and (2), and ultimately will influence the performance of the water well. Whether or not a cone will form depends on a source for air, the quality of **completion** and/or amount of **drawdown.**

(3) Conversion of **confined aquifers** to **unconfined aquifers.** For the conversion of a confined aquifer to an unconfined aquifer requires a source of air. No water can be produced unless the volume vacated by produced water is re-occupied by something, whether it be more water from a remote distance, or air. For air to re-occupy the vacated space there must be a source, and a communicable path between the aquifer and the source of air. If there is no air, or there is no communicable path to a source of air, there will be no conversion.

Under natural conditions, the usual confined aquifers do not have access to air except at distant **outcrops**, or if the completion of the well were faulty, or if air dissolved in water comes out of solution as pressure declines.

Air creeping into a confined aquifer as a result of the water table falling in outcrops will be discussed under **potentiometric surface (2).**

The possibility for air to communicate with a confined aquifer because of poor quality well completion is conditional. However, a means by which the conversion could take place would be for cones of depression from a number of producing wells to overlap or merge with one another. This would allow a layer of air to overlie the water and, therefore, allow air to take the place formerly occupied by water as water is produced. If the re-occupation were to take place, drainage of water in this manner would be by **gravity drainage.**

Coning universally is thought of as a result of overproduction due to a flow rate that is too high for the thickness of the aquifer, or as a result of faulty **completion** practices. All aquifers lying above the selected producing aquifer must be completely isolated from the producing aquifer, and from each other. If not, **crossflow** can occur between aquifers, and the water produced at the surface might include water from one or more of the other aquifers. To prevent this, the annular space between the

production casing and the face of all aquifers must be sealed, usually with cement, to ensure isolation and prevent **communication.** If the cementing is performed properly there will be no communicable path to air via the annular space. If the completion is faulty, not only might there be communication with air in the **aerated zone**, but there will be communication with other aquifers as well.

If the annular space between the production casing and the face of all aquifers has been properly completed and sealed, then the only other communication with air is through the annular space between tubing and production casing. This space usually is sealed by bolted fittings and connections at the ground surface. If leakage should occur, the water level in this annular space during the pumping operation should be prevented from falling to the level of the pump.

The air-water interface between the cone and the water is a depression in the **potentiometric surface.** Water production will continue as long as the potentiometric surface is above the pump, and as long as there is pressure to drive the water out of the rock. The cone might reach equilibrium with the production rate and stabilize, or the cone might continue to grow until air reaches the pump, at which time the pump will try to produce air.

(4) If the conversion from confined to unconfined aquifers were to take place there would be consequences. The benefit of the conversion where cones of depression merge is that there might be the possibility for a layer of air to grow in the upper part of the saturated aquifer. If the leakage of air were to continue, and in sufficient quantity, the layer of air would allow water locked in the aquifer to drain by **gravity drainage.**

However, depending on its depositional history the aquifer might have been formed by material transported by wind or water and deposited as sand dunes or sand bars. Air, because of its lighter density, would seek the higher elevations in the aquifer undergoing conversion. The consequence of this is that any wells drilled into the accumulation of air might incur production problems. New wells drilled into the higher elevations where air has become trapped will have a shorter beneficial life, and old wells will deplete early as air replaces water. See **depositional environment** and **sedimentary.**

Also, relative to depleting **confined aquifers**, see the discussion on flooding by the injection of compressed air under **drainage (2)**.

connate water: The adjective connate is from the Latin meaning born together, originated together, or deposited along with the sediment. Connate waters are waters entrapped within the pores or spaces between the grains or particles of rock constituents (**sedimentary** or extrusive **igneous**) at the time of their deposition. Connate water is derived from sea water, meteoric water, or ground surface water. It is not to be used interchangeably with interstitial water. All connate water is interstitial water, but not all interstitial water is connate water. Compare **interstitial water**.

conservancy district: A special taxing district, created by a vote of the district's electors, that has authority to plan, develop, and operate water supply and/or potable-water projects. **CSU**.

conservation: Providing protection for any part of our environment by placing limits on the use, waste, exploitation, and pollution of a natural resource; and by the reuse through reclamation or other treatment of a used resource for the purpose of stemming the exhaustion of a natural resource. Also see **preservation** and **environmental concerns**.

conservation district: A geographical area designated by the State Legislature for water management purposes with a board appointed by county commissioners. **CSU**.

conservation storage: The storage of water in a reservoir or other containment for later release for beneficial purposes.

consolidation: Pertains to the rigidity of sedimentary rock. The precipitation and growth of water borne minerals on and around the grains, particles, or fragments of sediment serve as binding material that increases adhesiveness and rigidity. Typical binding materials are authigenic cementing crystals of quartz and carbonates. Also see **cementation**.

consumer confidence report: An annual water quality report prepared for consumers by their supplier. **GWAC**.

consumptive use: Any use of water that permanently removes the water from the stream system. For irrigation, consumptive use can be water used by crops in transpiration and building of plant tissue.

contamination: The undesirable introduction of pollutants or other extraneous matter into a system free of impurities. Can occur in water wells from faulty completion practices. Also see **soil vapor intrusion.**

conversion of confined aquifers to unconfined aquifers: This is not a technical term, but it is a sometime behavior that is said to occur relative to depleting **confined aquifers.**

Confined aquifers have no **water table. Unconfined aquifers** have a water table underlying air at atmospheric pressure in the **aerated zone.** For the conversion of confined aquifers to unconfined aquifers to take place there must be a source of air and a communicable path to the air, and air must replace produced water. The drainage of water from the aquifer in this manner is by **gravity drainage** as long as air is continually replenished, and as long as mobile water is available. See **irreducible water.**

Some **hydrogeologists** look upon the conversion of confined aquifers to unconfined aquifers as a potential, beneficial occurrence. If it happens it is possible for water formerly locked in the aquifer to be released by **gravity drainage**, but there are consequences.

At present, there are three speculative proposals how air might enter confined aquifers for conversion to take place: (1) Air creeping in from distant outcrops. (2) Merging cones of depression. (3) Dissolved air coming out of solution as pressure declines.

There are conditions where this conversion can and cannot occur. In general, for air to exist in the producing well system, there must be some form of communicable path to air. Confined aquifers, if they contain renewable water, are recharged at distant outcrops. They have no other communication to air unless **completion practice** for the well is faulty. See a discussion on how this conversion could take place by faulty completion practice under **coning (3),** and a discussion on the falling water table at outcrops and consequent fall in potentiometric surface of **confined**

aquifers under **potentiometric surface (2).**

If the conversion were to take place, there would be consequences. See the pros and cons of this conversion in coning (4) and for the drop in the potentiometric surface in **potentiometric surface (3).**

Also, relative to depleting **confined aquifers**, see the discussion on flooding by the injection of compressed air under **drainage (2).**

conveyance loss: Water that is lost in transit from a pipe, canal, conduit, or ditch by leakage or evaporation. Generally, the water is not available for further use; however, leakage from an irrigation ditch, for example, may percolate to a groundwater source and be available for further use. **GWAC.**

corrosion: (1) The chemical, electrochemical, or erosional destruction of metal or its surfaces by its natural or unnatural environment.

(2) A process of erosion whereby rocks and soil are removed or worn away by natural chemical processes, especially by the solvent action of running water, but also by the reactions, such as hydrolysis, hydration, carbonation, and oxidation. **NSSH.**

corrosivity index: One of the methods for assessing the scale dissolving (corrosive) or scale forming potential of water. A positive number indicates a tendency to deposit calcium carbonate. If the result is negative, it is an indication that the water will dissolve calcium carbonate and enhance corrosion. Also see **Langelier Index. CSU.**

crossflow: (1) The undesirable condition of fluid-flow out of one or more permeable **strata** into one or more thief strata. In aquifers, it can result in the depletion of one or more strata and the loss of integrity and/or contamination of others when water flows out of one into another. A condition that often occurs in water wells when faulty **completion** practices fail to isolate permeable strata. Also see **channeling.**

(2) The undesirable condition in a producing water well when water from a restricted or unauthorized aquifer flows behind

casing to the level of the authorized aquifer and is produced, consumed or sold along with the water from the approved aquifer. A thief condition that often occurs in water wells when faulty completion practices are accepted and fail to isolate unapproved permeable strata and, therefore, fail to prevent production from unapproved aquifers. This condition can result in the unauthorized depletion of an unapproved aquifer.

(3) In oil or gas wells the **production casing** that passes through the **surface casing** must be completed properly. If not completed properly, oil or gas and sometimes salt water from producing wells, or **shut-in** wells, or capped uneconomical wells, or plugged and abandoned wells, under pressure from the formation, can fill the hole or enter channels in the annular space between the production casing and the face of the drilled hole, and thus allow **communication** and ultimate contamination of any or all unprotected aquifers. See **completion.**

critical year: Usually considered a year in which the annual precipitation was considerably less than average and runoff in most of the streams was low. The critical year is used to test the dependability of water rights under "worst case" conditions.

cryptosporidium and **giardia:** Found in Colorado's rivers and streams, cryptosporidium and giardia are microscopic organisms that, when ingested, can result in diarrhea, fever and other gastrointestinal symptoms. **GWAC.**

CSU: Colorado State University, Cooperative Extension.

cubic foot per second: cfs. A unit of water measurement equal to the flow of one cubic foot of water each second. Equivalent to 448.8 gallons per minute or 1,984 acre feet per day.

darcy, darcys, darcies: The accepted unit of measure for **permeability** as proposed by Darcy. The permeability of a medium to allow the flow of one milliliter per second of fluid of one centipoise viscosity through one square centimeter under a pressure gradient of one atmosphere per centimeter.

Darcy's equation: Often referred to as Darcy's Law.

(1) A simplified version of Darcy's linear equation is

$$q = (kA / \mu) \times (\Delta p / \Delta d)$$

where, in aquifers: q = fluid flow rate of ground water, k = **absolute permeability** of the aquifer to fresh water , A = cross-sectional area of the cumulative flow paths within the aquifer, μ = **viscosity** of fresh water, Δp = initial pressure difference that provides the energy for ground water to flow across distance Δd. This is an equation that is commonly applied to liquid flow rates in linear lengths of rock; short, long, vertical, horizontal, and pipelines.

It might be easier to understand this equation if it is rewritten as:

$$q = (kA / \mu \Delta d) \times \Delta p$$

In this rewritten version, the total quantity within the parentheses constitutes a fraction with a value lower than 1.0. And, the fraction contains all the conversion units to convert flow rate to pounds pressure per square inch, or the reverse conversion from pressure to flow rate. The A and the μ essentially are constant. The k can vary throughout the aquifer as the quality of the aquifer changes. The expression k/μ is **mobility**. It can be seen that as distance Δd increases from some starting point that the fraction within the parentheses becomes smaller. Also, it can be seen that the fraction decreases linearly with distance and might have variations in linearity when and if there are variations in k. As distance from a water source increases, the pressure remaining to push water into the borehole decreases, as does the flow rate. In the use of the equation, the term Δp represents the original energy to cause water to flow and is determined by the difference in pressure between two different elevations. One is the elevation of the water table at the recharge area (source) and the second is the elevation within the aquifer where water emerges. But, the initial Δp is a **gravity drainage** potential. After the original Δp has been reduced over distance Δd a new value for Δp is the result. This is the **artesian pressure** between the elevation of the **potentiometric surface** at the well site and the elevation of water emergence from the aquifer. The water drive now has only a fraction of the energy of the initial gravity drive.

When the potentiometric surface falls, the Δp diminishes, and when the potentiometric surface falls to the depth where water emerges from the aquifer, the Δp diminishes to zero. The flow rate of ground water diminishes right along with the Δp.

(2) Darcy's radial equation:

$$q = (kh / \mu) \times (\Delta p / \ln(re / rw))$$

where: q = fluid flow rate, k = **absolute permeability** to water, h = aquifer thickness, μ = **viscosity** of fresh water, Δp = pressure difference across the drainage radius of the formation to the well bore, *re* = effective drainage radius, *rw* = effective well bore radius (gravel packed radius or fractured radius as applies). This is an equation that is commonly applied to liquid flow rates in producing wells.

(3) There are at least two forms of Darcy's equation. The two most recognized forms are seen in parts (1) and (2) above. Part(1) pertains to linear distances in aquifers or pipelines over distances of from inches to many hundreds of feet or more. Also applies to vertical distances as well as horizontal distances. For water to flow, it will obey whichever relationship fittingly applies.

The flow rate of water is directly related to the pressure that drives the water. And the driving pressure is a function of two expressions seen on the right side of each equation. Both expressions are based on an energy source that creates an initial total Δp. Because it takes part of that total energy to move water within an aquifer from one place to another over distance Δd, not all the initial energy is available for water production. Darcy's equation(s) modifies that *total* pressure difference to a *net* available pressure difference that results in a lower calculated rate of flow. Although Darcy's equation has many applications over distances or lengths short and long, horizontal and vertical, one significant function of the equation is that it accounts for the pressure loss in moving water from a distant source to the site of the unopposing borehole. After the pressure loss, there is a decreased net pressure drive resulting in a decreased potential flow rate. Once the opposition to water movement has been overcome, if no net pressure drive remains, then there will be no water production. The same logic also applies to short distances from points inside the aquifer to a point inside the well bore of a producing well. It also applies to different forms of drainage. See **resistance to flow** and **drainage (2)(a)** in particular. It is a very useful equation to demonstrate the factors that influence liquid flow.

Not a part of Darcy's linear relationship, but a factor in determining the rate that water emerges from the drilled face of the aquifer is **backpressure**, which is a function of **drawdown.** Back pressure is a part of Darcy's radial relationship. See also **pumping process** and **withdrawal process.**

In a word statement relative to water, Darcy's equations read:

The flow rate of water is a function of the total energy available to move that water, decreased by the fraction of that same energy required to overcome the opposition to the movement of that water.

For more information about Darcy's equation and the individual hydrogeological terms appearing within Darcy's equation, see the detailed discussion under **hydraulic conductivity.**

Henry Darcy developed his equation ca. 1856. His equation has become law and provides the foundation for work in hydrogeology and petroleum engineering.

Dawson aquifer: The uppermost formation of the Denver Basin aquifer system. The upper part of the Dawson formation is considered to be tributary. The Dawson aquifers are composed of sandstone and conglomerate. **Douglas Co.**

decree: An official document issued by the Court defining the priority, amount, use and location of a water right or plan of augmentation. When issued, the decree serves as a mandate to the state engineer to administer the water rights involved in accordance with the decree. **Douglas Co.**

decreed water right: A court decision placed on a water right that is then administered by Colorado's Water Resources Department. **CSU.**

deep percolation: The penetration of surface water, by **gravity**, below the maximum effective depth of the root zone. **Douglas Co.**

deflection: The angle in degrees, or deviation, from vertical in a slant hole or in a directionally drilled hole.

density: Mass per unit volume. Units are either g/cm^3 or mg/liter depending on application. Compare **specific gravity.**

Denver aquifer: The Denver formation underlies the Dawson formation and the aquifers are composed of interbedded sandstone, siltstone, and shale; and contains some coals. **Douglas Co.**

Denver Basin: A large groundwater basin of sedimentary rock formations containing four principal aquifers, the **Dawson, Denver**, **Arapahoe** and **Laramie-Fox Hills.** The water basin extends from Greeley on the north to Colorado Springs on the south, Limon on the east to the foothills on the west. Ground water contained within the Denver Basin aquifers is considered to be either nontributary or not-nontributary under the Colorado Water Rights System. **Douglas Co.**

deplete: To use, exhaust, exploit, or consume to excess, usually at a rate faster than the water is replenished. In an aquifer, in compliance with Pascal's Law of pressure transmission, a decrease in pressure at one place of withdrawal can be transmitted to all other parts of the aquifer system, subject to **communication** and **permeability.**

depleted: (1) In aquifers immediately underlying the zone of aeration (**unconfined aquifers**), it is the condition that exists when **gravity drainage** causes the air-water interface to drop to the level of water emergence from the aquifer. Water no longer can be made to flow into the well bore under this condition. This aquifer is depleted of **mobile water** above the level of the air-water interface, and the total water volume **in place** has been reduced. Also see **aerated zone**, **drainage (1)**, **aquifer (1)** and **irreducible water.**

(2) Relative to aquifers that have no communication with the

aerated zone (**confined aquifers**), it is the condition that exists when water pressure in the aquifer has been dissipated or exhausted to the extent that water in the aquifer no longer can be made to overcome both back pressure and resistance to flow out of the rock and into the well bore. This aquifer is *pressure depleted*, but water saturation is unchanged and the total water volume **in place** has not diminished, and is the same as before production began. Relative to depleting **confined aquifers**, see the discussion on flooding by the injection of compressed air under **drainage (2)**. Also, see **Darcy's equation** which determines available pressure, and see **back pressure**, **in place**, **resistance to flow**, **movable water**, **drainage**, and aquifer (2).

depletion rate: The true depletion rate is the net rate of water use, over time, from a stream or aquifer.

(1) Of a water well. Production volume minus upstream, natural or unnatural recharge volume over a specific time period.

(2) For irrigation and municipal uses, the depletion is headgate or well-head diversion less return flow to the same stream or aquifer.

depletion time: Time indicating how long it would take the watershed or the groundwater system to dry out if surface runoff or groundwater replenishment (recharge) were stopped from an instant onward, and if outflow was maintained at the rate it had at that instant. Depletion times of surficial water usually are of the order of hours or weeks. They may run into months or years if the river basin includes large lakes. Depletion times of aquifers are usually of the order of tens to hundreds of years. As a consequence, rivers react quickly to precipitation and to the extraction of water, whereas groundwater systems react very sluggishly to these events. **GWAC.**

deposit: (1) An accumulation of sediment of any material and from any source to form a bed or layer of rock.

(2) To put, drop, lay down, or leave in place.

depositional environment: The environment in which sediment is deposited.

The five categories are: marine (from seas or ocean), aeolian or eolian (wind borne), alluvial (river borne), deltaic (formed at the terminus of a river), and interdeltaic (formed between river deltas).

depth datum: The location at the surface of the ground or above the surface of the ground from which all depth measurements are referenced in a drilled hole.

depth of invasion: This is the radial depth within the formation, bed, or stratum that drilling-mud filtrate has penetrated.

depth to base: The depth to the base of an aquifer is the vertical distance from the ground surface to the base of the aquifer. **Douglas Co.**

depth to water: The depth from the ground surface to the water table. See **water table.**

designated ground water: Ground water which, in its natural course, is not available to or required for the fulfillment of decreed surface rights, and which is within the geographic boundaries of a designated ground water basin. **CSU.**

designated ground water basins: Those areas of the state established by the Ground Water Commission located in the Front Range and Eastern Colorado. **CSU.**

detrital clay: Clay particles or crystals that occupy space within the pores of a rock. Can be both authigenic and non-authigenic types. Detrital clay often is dissolved in interstitial waters and later the ions recombine to form crystal growths on the grain surfaces at the same location or at a different location. See **authigenic.**

detrital sediment, detritus: A term for rock and mineral fragments, accumulating in sediments, that have been detached or removed by mechanical erosion or mechanical weathering of previously existing rocks.

developed water: Water that has been brought into a water system by manmade means, where it would not have entered the water system by natural means.

deviated hole: An intentionally drilled slant hole or directionally drilled borehole under controlled conditions.

diagenesis: The chemical, biological, or physical changes that sediments undergo to become consolidated rock, or in some cases to create secondary porosity. Such changes result from compaction, cementation, recrystallization, dissolution, or replacement.

diagenetic: The process of altering physical properties of rock by dissolution, precipitation, or geomorphology.

1. The process of enlarging existing pores or creation of additional porosity, cavities or vugs by further dissolution of rock.

2. Creation, by growth, of constituents within the interstices of gravel, sand, or rock, that were formed, or were generated, from saturated solutions. Particularly, crystals of minerals that are found adhering to and coating the walls of the pores within a host rock such as sand. Typical diagenetic minerals are quartz, carbonates, and clays. In aquifers, the presence of diagenetic crystals, particularly those of clay, can cause flow problems in both injection and production wells. **Authigenic** crystals are diagenetic crystals that have been formed by dissolution of detrital sediment and re-crystallization at the same location where they are found. In aquifers, the presence of authigenic crystals, particularly those of clay, can cause flow problems in both injection and production wells.

diameter of invasion: In the borehole environment, the radial diameter that the specific drilling mud filtrate penetrates a formation, bed, or stratum during the drilling process.

dip: The angle that a bedding plane makes with the horizontal.

direct flow right: Water diverted from a river or stream for use without loss between diversion and use except for natural losses, such as **evaporation**, settling, **percolation**.

directional drilling, directional hole: See **deviated hole**.

dirty: Describes the presence of appreciable amounts of clay, shale, or silt which is different in mineral nature from that of the host rock. Can describe gravel or sand with appreciable amounts of **clay** and **shale**.

discharge: (1) To force or direct flow out of.

(2) Rate. The volume of water passing a specific point within a unit of time. Units of discharge commonly used include cubic feet per second (cfs) or gallons per minute (gpm).

(3) To force out of, empty, expel, eject sometimes with explosive force. Erupt.

(4) See also **discharge area**.

discharge area: An area where ground water is lost naturally from an aquifer through springs. The water leaving the aquifer is called *discharge*. **GWAC.**

discontinuity: (1) Any form of interruption or break in the depositional sequence or depositional pattern of a sediment. See **unconformity.**

(2) Any form of interruption or break in the permeable pathway of the water stream in a **confined aquifer** or **pass-through aquifer.**

disinfectant: An agent or chemical solution, such as chlorine or iodine, or ozone, or ultraviolet light that kills disease-causing microorganisms. Sometimes the chemical disinfectant (chlorine bleach solution) is very corrosive to the casing and downhole hardware.

disinfection by-products: Chemicals, such as total trihalomethanes, formed from naturally occurring humic or fulvic acids and the disinfectant used in treating water. **GWAC.**

dissociation: The breaking up of a compound into its simpler components such as molecules, atoms, or **ions.** Results from the action of some form of energy on gases and from the action of solvents on substances in solutions. **SPWLA.**

diversion records: Records of the daily flow in cubic feet per second for a ditch or other diversion structure during the irrigation season, compiled by the District Water Commissioner. Diversion records are on file and available for review by the public at the State Engineer's Office in Denver, Colorado.

diversion, divert: Removing water from its natural course or location, or controlling water in its natural course or location.

(1) On the surface of the ground, by means of a ditch, canal, flume, reservoir, bypass, pipeline, conduit, pump, or other structure or device.

(2) In an aquifer, by barriers produced by decreased porosity or permeability, increased local water pressure, or by stratigraphy.

divide, drainage divide: The boundary between one drainage basin and another. **GWAC.**

division engineer: The state engineer's principal water official in each of the seven water divisions. **CSU.**

dolomite: (1) A mineral, calcium magnesium carbonate ($CaMg(CO_3)_2$).

(2) A sedimentary rock consisting primarily of the mineral, calcium magnesium carbonate.

domestic water use, domestic well use: Water used for drinking and other purposes by a household, such as from a rural well. Domestic use permits normally allow limited irrigation and outside watering uses. **GWAC.**

Douglas Co.: Douglas County, Colorado.

downgradient: Downstream.

downhole: A term to describe the location in the well bore of certain activities or equipment.

drainage: Relative to aquifers and reservoirs. When water (also oil or gas) is produced from a formation the space vacated by the produced water must be re-occupied otherwise the **pressure gradient** between the water in the well bore and the water in the formation will rise sharply depending on existing formation pressure. The increased pressure gradient might cause **coning** to take place with damaging finality. (Side note. The water-well pump cannot draw water to the well bore by *suction*. A vacuum, even if it could be created, cannot drive water to the well bore because a vacuum is neither a source of energy nor a form of force. See **suction**, **pumping process** and **withdrawal process**.)

Drainage is the means by which water, in the case of aquifers, is driven out of the formation into the well bore. Drainage cannot be sustained without reoccupation of the space vacated by produced water. Air is what re-occupies the space vacated by produced ground water. Without reoccupation, water production will become sporadic and ultimately will cease. The combined processes of *producing water* from the formation and *reoccupation of the vacated space* is called drainage; and, it is *how* reoccupation takes place that defines or distinguishes the kind of drainage.

There are a number of different methods to produce water from aquifers and reservoirs. Drainage pertains to the type of force or method, usually at the location of a producing well, that causes water to flow to the well bore. All flow rates are subject to **Darcy's equation.** See also **recovery.**

Different mechanisms for drainage can be:

(1) **Gravity drainage.** This is a local form of drainage that can take place in aquifers underlying and adjacent to the **aerated zone.** Here, air at atmospheric pressure replaces the water that has been produced and, without replenishment, the **water table** will be seen to drop or decline as water production continues. Gravity drainage can take place *only* where there is a difference between the **densities** of the produced fluid and the replacing fluid. The driving force is **gravity.** The energy to force the water into the well bore comes from the height of the water table above the level of water emergence from the aquifer (**hydrostatic head**). **Buoyancy** moderates the effectiveness of gravity. Gravity drainage commonly occurs in **unconfined aquifers.** See **aquifer (1)**, **buoyancy**, and **water table.**

(2) Other drainage methods result from any of the natural driving forces occurring within **confined aquifers.** Such force can be: (a) **hydraulic pressure** derived from a remote **hydrostatic load**, and transmitted hydraulically, where the pressure gradient toward the borehole is maintained by the height of the water table (at the remote location) above the level of water emergence from the formation, and produced water is continually replaced by **renewal** water;
(b) augmentation of water supply by expansion of water (see **bulk modulus**) and through compaction of **clay shales** in overburden (see **compaction (2)**), both resulting from depletion of pore pressure by water production (also see

subsidence); (c) dissolved gases coming out of solution as pressure is decreased, and produced water is replaced by expanding gases; (d) expanding gas that has accumulated (by virtue of its low density) in a stratigraphic trap and produced liquids are replaced by the expanding gas;(e) **abnormal pore pressure** that drives water to the well bore as long as the pore pressure exceeds **back pressure**;(f) by the unnatural process of recharging, to artificially replenish the produced water or its pressure by any form of **augmentation**, or by a **flood** process wherein a less valuable fluid is injected into the **aquifer** or **reservoir** to maintain sufficient pore pressure to increase or sustain production of the more valuable fluid. Flooding is a means of recovering a geofluid that is not recoverable by natural means. In aquifers where water is locked in the rock and will not drain by natural methods, air flooding might be implemented. This is a method where compressed air is injected into the aquifer to increase pore pressure and maintain producing rates. The air occupies pore space vacated by water allowing water production to continue. In aquifers, this would be an air flood operation. In depleted oil reservoirs the injection of air would be a thermal method usually referred to as a fire flood operation. The injection of air into an oil-bearing reservoir supplies the oxygen to start a burn by spontaneous combustion. The resulting hot gases produced would maintain pressure and heat the rock, decreasing the viscosity of the oil and driving the oil ahead of the burn front. See **flood** and **aquifer (2)** and **(3)**, and **recovery**.

(3) The term *drainage* also can be related to the percentage that water, oil, or gas has been withdrawn from a reservoir. See **reservoir** and **recovery factor**.

drainage area, drainage radius: Production of water by a water-well pump increases **drawdown** and, therefore, reduces the back pressure in the well bore. This reduction in pressure in the well bore produces pressure gradients in all directions from the well, allowing water pressure in the aquifer to drive water toward the well bore. The effectiveness of drainage and, therefore, the drainage area around the well is related to conditions influenced by a number of factors, among them are: (1) drawdown, (2) resistance to flow, and (3) water pressure in the rock. See **drainage**, **drawdown**, **pressure gradient**, and **resistance to flow**. See also **Darcy's radial equation**.

drainage basin: See **basin (2).**

drawdown: In a producing water well. (1) It is the difference in pressure between the back pressure under static conditions and the back pressure under producing conditions. See **back pressure (1)** and **(2).**

(2) The difference in the depths inside the well bore between the water level at static conditions and the water level under producing conditions.

(3) The theoretical maximum drawdown occurs when the water level inside the casing under producing conditions falls to a steady-state level just above the level of the pump intake ports. If the dynamic water level falls to the level of the intake ports, water production will cease. Also compare **coning.**

(4) Sometimes refers to the difference in depths between the original static water level in a well and the present static water level, thus an indicator related to the decline or rate of decline in formation pressure.

drift: A term sometimes used to describe a flow of ground water caused by hydrostatic force due to a naturally existing regional gradient. **Douglas Co.**

drilling mud: Rotary rigs utilize a drilling-fluid mixture to facilitate the drilling operation. Drilling mud is pumped into drill pipe and down to the bottom of the borehole where it passes through the drill bit and returns to the surface through the annular space between the drill pipe and the face of the drilled formation. The mud is saved in a mud pit from which it is recycled into the drill pipe.

Drilling mud serves a number of purposes: (1) It cools and lubricates the bit; (2) it removes cuttings from the drilled hole and brings them to the surface where they can be identified and analyzed; (3) with its designed density, it can provide sufficient **back pressure** to prevent flow of geofluids into the drilled hole (sometimes hydrocarbons can discharge with disastrous consequences); (4) helps to prevent collapse of the drilled hole by the back pressure it produces; (5) can be designed by engineering its chemistry and salinity to minimize the penetration of mud filtrate into the formation, and to minimize the absorption of mud filtrate or water by clays in the formation; and (6) provides the necessary medium for the operation of numerous well-logging instruments.

drill pipe, drill stem: Rotary rigs use drill pipe to direct drilling mud down to and through the drilling bit. The drill pipe consists of numerous joints of pipe screwed tightly together, ending with the appropriate fitting and drill bit for the situation, underground conditions, and formations to be penetrated.

drive, drive mechanism: Provides the natural or unnatural energy that sustains the pore pressure or hydraulic water pressure that forces water in rock to overcome the **back pressure**, and the **resistance to flow** within the rock, to flow into the well bore. See **drainage**, **hydrostatic load**, **hydraulic pressure**, and **pressure gradient**.

drop pipe: See **tubing**.

dynamic: In a state of motion. In water wells, it means active production or injection is taking place. Water is in motion under hydraulic pressure, either flowing through the pores of an aquifer and into the well bore, or being forced to flow into a formation, bed, or stratum.

dune: A low mound, ridge, bank or hill of loose, windblown, subaerially deposited granular material, generally sand, either barren and capable of movement from place to place, or covered and stabilized with vegetation. **NSSH.**

duty of water: The total volume of irrigation water required to bring to maturity a particular type of crop. It includes consumptive use, evaporation and seepage from ditches and canals, and the water eventually returned to streams by percolation and surface runoff, usually expressed in acre-feet per acre. **Douglas Co.**

dynamic water level: In a water well, under producing conditions, it is the depth at the surface of the column of water standing in the well casing. See **water level (2).**

ecosystem: A limited and specific micro-community within the environment.

effective permeability: See **permeability (2)**.

effluent: (1) Relative to any form of treatment of liquids, any liquid that flows out. Can be a filtrate.

Effluent water, if it can be reclaimed through filtration and chemical means, is reclaimed for reuse and may be recycled a number of times through additional beneficial uses, or returned. Effluent is a downstream product that has been taken from the original **renewable water**, i.e. the original source of effluent is renewable water. Effluent, in any quantity, has reduced renewable water by that same quantity.

Effluent is an after product of beneficial use. The amount of effluent is dependent on the efficiency or inefficiency of the beneficial use and reclamation processes. No matter what is done to the effluent, it cannot add to or increase the renewable water supply from whence it was taken, but it can minimize waste by reuse and contribute to preservation by downstream replenishment. Reclamation and recycling are important parts of **conservation** and **preservation**, but neither is part of the renewal process. Renewable water can be renewed only through the **hydrologic cycle** of water movement of which precipitation is the key to the renewal and sustainability of our water supply. See **hydrologic cycle.**

In a hypothetical example, when or if there is a break in the **hydrologic cycle** and the **renewal** process ceases, and when stores and pressures are depleted, there will be no more downstream effluent to be reclaimed and reused. Effluent, therefore, depends on the renewal process, but the renewal process does not depend on effluent.

(2) Liquid sewage or other wastewater discharged with or without treatment into the environment.

(3) Relative to a **drilling mud**, it is the **mud filtrate** that penetrates the formation during the well-drilling process.

effluent exchange: The practice of exchanging suitable wastewater effluent for other water sources, without causing injury to other water rights, as a replacement source for diversion of water farther upstream that would otherwise have been out of priority. **CSU.**

elasticity: See under **bulk modulus.**

end cap: A cap or nose placed at the downhole end of the casing to prevent sediment from entering the casing.

energy: Non specific. (1) Ability to perform work or provide force. Examples: **artesian head**, pore pressure, water pressure, hydrostatic pressure, heat.

(2) A form of power. Kinetic, gravity, hydraulic, electric, wind, water, solar.

environment: (1) Our natural surroundings of earth, air, water, and other natural resources that sustain life and maintain equilibrium in the quality of life.

(2) The immediate surroundings of the well bore at the depth of interest in a water well.

(3) The natural conditions existing at the time when an event takes place or took place.

environmental concerns: A recognition of the fragile equilibrium provided by our environment, and that without smart and careful management that equilibrium can become unbalanced, natural resources damaged, and the quality of life greatly diminished. Has been explicitly endorsed by the General Assembly as a legitimate concern in land use planning by local governments. Involves **preservation** and **conservation**.

eolian: Pertains to material transported by and deposited by wind. See **aeolian**.

ephemeral stream: Generally a small stream, or upper reach of a stream, that flows only in direct response to precipitation. It receives no protracted water supply from melting snow or other sources and its channel is above the water table at all times. **NSSH**.

equity: As it applies to ownerships of ground water in the different aquifers. It has been legislated that the ownership of ground water is to be allocated upon the basis of the ownership of the overlying land. But, the reality is that the quality of the aquifers from which the water comes is not all equal and the efficiency that rock releases its hold on water can differ from location to location and from aquifer to aquifer. A true measure of equity is not how much water is **in place**, but how much water can be recovered or can be produced by employing normal methods. See **equity determination**.

equity determination: Although it is the intention of legislation to be fair, the de facto result is that fairness does not always follow. Additionally, water knows no political or surface boundaries. As a result, water migrates across surface boundaries, flowing from a region of higher **formation pressure** to a region at lower formation pressure such as the drainage area of a series of wells, or drainage area of a dominant producing well. When this migration is caused by water production from another well, well-to-well interference can result in decreasing energy or **pore pressure** at inferior wells. This interference, in the form of pressure depletion, can reduce the producing life of a well, resulting in a decrease in equity and can be recognized by the lowering of the **static water level**(s)in a nearby **monitoring well**(s). See **Darcy's equation (3)** and **water level (1)**.

The Colorado Supreme Court holds that ground water is a public resource. Technically, the ownership of the waters produced belongs to the owners of land overlying the aquifer in proportion to their predetermined equities. The oil and gas industry recognized this problem of ownership many years ago and devised formulae to determine equities for all owners or leaseholders of land overlying shared reserves or resources. Along with the areal extent of overlying land and aquifer thickness, other factors influencing the length of time and efficiency with which water can be produced, and ultimately controlling the quantity of water that can be recovered are: formation pressure, **porosity**, **permeability**, grain size and surface area, clayiness, mineralization, **consolidation**, connectivity, **irreducible water**, etc. Only by addressing as many of these factors and their changes, as are necessary and appropriate, can equity and injury be defined. See **Darcy's equation**, **drainage**, **deplete**, **clay**, **fines**, **permeability**, **pore pressure**, **recovery factor**, **resistance to flow**, **Senate Bill 5, withdrawal process**.

erosion: A natural process by which soil or ground surface is weathered away by the action of water, wind, freezing or landslides.

eutrophication: The process of surface water nutrient enrichment causing a water body to fill with aquatic plants and algae. **CSU**.

evaporation: (1) The physical process by which a liquid or solid changes to a gaseous state. A phenomenon that occurs at the surface usually between liquids and gases. Near the surface of liquids, and some solids such as ice, some molecules are continually breaking away from the cohesive forces that bind them. See **surface tension**. At the same time some of the molecules in the vapor phase created above or outside the surface of the cohesive substance are returning. When the conditions are such that the number of escaping molecules exceeds the number of returning molecules, evaporation will take place and the volume of the cohesive substance will diminish. See also **sublimation.**

(2) When the number of molecules escaping a liquids cohesive surface exceeds the number of returning molecules, a vapor pressure is created in the gaseous phase. When an equilibrium is reached between escaping and returning molecules the gaseous phase will be saturated. When the vapor pressure equals the ambient pressure or atmospheric pressure, boiling will occur.

evaporite: A mineral that has been precipitated from a highly concentrated water solution as a result of evaporation.

evapotranspiration: The combined processes by which water is transferred from the earth surface to the atmosphere; evaporation of liquid or solid water plus transpiration from plants. See **Consumptive Use.**

exchange: Of water. Diverted out of priority at one point of diversion by replacing it with a like amount of water at another point of diversion. Compare **effluent exchange.**

exempt uses: Any recognized uses that are not subject to administration under the priority system. **CSU.**

exempt well: Exempt wells do not require an augmentation plan, while most non-exempt wells do require an augmentation plan. Exempt wells are usually limited to 15 gpm and require non-evaporative wastewater systems. See also **non-exempt well. CSU.**

extrusive: A term that describes **igneous rock** that has been formed from magma that has cooled and solidified upon reaching the surface or near surface of the ground. Also see **magma.**

fault: A discrete break or fracture across strata or a stratum where the rock on one side of the break has been displaced upward, downward, or laterally relative to the other.

federal reserved rights: An implied water right that occurs when the federal government withdraws its land from the public domain and reserves it for a federal purpose, the government, by implication reserves appurtenant water then unappropriated to the extent needed to accomplish the purpose of the reservation. **CSU.**

field capacity: It is the amount of water remaining in soil or rock against the pull of **gravity**. It is sometimes limited to a certain drainage period (2 or 3 days) thereby distinguishing it from **specific retention**, which is not limited by time. **GWAC.**

fillup: Sand, silt, fines, and other materials that are produced from the aquifer, along with water, that are not pumped to the surface, but fall to the bottom of the cased well bore.

filter: (1) A device to screen or otherwise separate colloidal particles and other sediment, sometimes living microorganisms, from water.

(2) To screen or otherwise separate colloidal particles and other sediment, sometimes living organisms, from water.

(3) Relative to drilling mud, to filter the solids from the drilling mud. The effluent is a *mud filtrate*. During the drilling process, drilling mud is filtered by the face of the drilled formation, and drilling mud filtrate penetrates the formation to a radial depth referred to as the *depth of invasion*.

filter cake: Relative to drilling muds. During the filtration process, mud solids are filtered from the drilling mud, leaving a cake of mud on the face of the filtering medium.

filter loss, filtration loss: The amount of effluent or filtrate that can pass through a filtering medium in a specified length of time.

filtrate: (1) The effluent of a water treatment process.

(2) Mud filtrate. See **filter (3)**.

(3) A percolate. See **percolate (2)**.

fines: A generic term referring to fragments or particles of rock too minute to be categorized, but can accumulate to occupy space in the pores of rock, thus impeding water flow. In a well bore, if the fines are not pumped out with the water, they can settle and accumulate at the bottom of the hole.

firm annual yield: The yearly amount of water that can be dependably supplied from the raw water sources of a given water supply system. **CSU**.

flaming water: This is not a technical term, but it is a sometime occurrence relative to ground water used for domestic purposes. This term gets its name from well water that flames when a source of ignition is placed near. The water will flame if flammable natural gasses are dissolved in the water and come out of solution when the confining pressure is relieved, such as by turning on a faucet or hydrant. The natural gas that emerges from or with the water is methane or a composite of methane and other gases. Go to www.colorado.gov/cogcc or http://cogcc.state.co.us for further information.

The approximate source of the gas can be determined from the composition of the gas, i.e. biogenic or thermogenic. The **COGCC** is able to differentiate between biogenic and thermogenic methane using both stable isotope analysis of the methane and compositional analysis of the gas. It is very helpful to know the source of the gas, but it is unlikely that flammable gas will find its way into the produced water unless there is a breakdown in aquifer isolation, or a vertical fracture (natural or manmade) connects the source of the gas to the aquifer. How a breakdown in isolation can occur is explained in **completion (6)**. Also, see **isolation**, **methane**, **biogenic methane**, and **thermogenic methane**.

flood: (1) An artificial or manmade means to inject fluid (a gas or liquid) into a permeable water-, oil-, or gas-bearing stratum being depleted, to increase or maintain the pore pressure or energy required to drive the natural fluid out of the rock into a remote well bore. Highest efficiency occurs in reservoirs where boundaries are finite and increased pore pressure can be maintained over time. The increased pore pressure finds relief by driving the reservoir fluid to remote producing wells. Lowest efficiency occurs in permeable stratum where any increase in pore pressure can find a natural form of relief and is dissipated. See also discussion of flooding under **drainage (2)**.

(2) An artificial or manmade means to inject fluid into a stratum being depleted to increase the pore pressure and stem subsidence.

(3) At the ground surface. The overflow of rivers and streams or the inundation of lowland by a large amount of water.

flood plain: A low area of nearly level land adjacent to a stream or other water course which is subject to flooding. Often delineated on the basis of the 100 year storm event. **CSU.**

flow, flow rate: See **Darcy's equation**, also see **discharge (2)**.

fluid level: All gases and liquids as they exist at standard conditions of temperature and pressure, or at the usual conditions of temperature and pressure, are fluids. In common usage, in all wells, fluid level means liquid level.

fluid loss: See **filter loss**.

flume: A sloped channel that is utilized to convey water and is commonly constructed of wood or concrete. Specialized flumes are used to measure flow (e.g. Parshall flume) by means of a calibrated opening or cross-section. **GWAC.**

flushed zone: Relative to the drilling process in an aquifer, **mud filtrate** penetrates the aquifer and fully displaces the water present in the pores. The zone where the displacement or flushing process has been most efficient is referred to as the flushed zone. Here, all mobile water has been displaced by mud filtrate.

fluvial: Of or pertaining to rivers or streams; produced by river action. Compare **alluvial. NSSH.**

flux: Refers to the concentration of flow. It is the quantity of material or energy transferred through a system or a portion of a system in a unit time and is called mass flux. If the moving matter is a fluid, the flux may be measured as volume of fluid moving through a system in a unit time and is called volume flux. For most hydrogeologic applications we desire to know the flux per unit area of a system rather than the flux of the entire system; the flux per unit area is called the flux density. **GWAC**. Also see **hydraulic conductivity** and **transmissivity**.

force: (1) The power or energy required to change the motion of material.
Pressure applied over a large area can constitute a driving force.
Water pressure in the pores of a rock provides the force necessary to drive water from the higher-pressure environment of the formation to the lower-pressure environment in the well bore. See **energy**, **hydraulic pressure**, **hydrostatic load**, and **pressure gradient**.

(2) See also **gravity** as a force.

formation: Often used as a generic term to describe the earthen environment of the borehole without regard to mineral composition, consolidation, permeability, or strata. More specific, it is a named, recognizable and mappable rock division consisting of a distinctive series of similar strata made up of similar minerals, of similar age, from a similar source, and exhibiting similar properties.

formation damage: Damage to a formation or to a specific aquifer can result from any action that disturbs the static equilibrium that exists within the bed. Static equilibrium can and will be disturbed by any dynamic action brought about by drilling the hole, producing water, or injecting water. The damage to aquifers or other beds often occurs where clays are present in their different mineralized forms. Formation damage sometimes can be reversed. See **acid stimulation**, **acid treatment**, and **brushpiling**.

(1) In the well bore environment. During the drilling process, the pressure of the drilling mud usually exceeds the pore pressure within the aquifer. The **spurt loss** from the drilling mud, and mud filtrate, will invade the aquifer to a specific radial distance depending on the **permeability** of the formation and the water loss of the drilling mud. The filtrate, and particularly the spurt loss, penetrating the pores produces fluid movement and shear inside the pores, and sometimes forces mud solids into the pores. The shear can weaken and break off fragile filaments from clay crystals that can **brushpile** at pore throats, and the mud solids can plug pores and pore throats, with the result that subsequent

water flow can be drastically reduced.

If lost circulation should occur while drilling, the condition might aggravate the situation just described. See **lost circulation.**

(2)In the well bore the production of water produces a pressure gradient toward the well bore and this flow of water produces a hydraulic shear within the pores of the aquifer. Injection of water is an even more difficult process. During production of water, the fines and other undesirable constituents are flushed out of the aquifer. During injection, the constituents and obstructive materials are forced into the aquifer. During production, when the production rate is too high, the force of the flowing water can break off fragile filaments of clay crystals, and these in turn can brushpile in the pores and pore throats, thus obstructing flow and reducing the water production rate. Where these clay crystals are found, the number of perforations in the casing must be increased and/or the length of the perforated interval must be increased, thus reducing the flow rate in the near environment of each perforation. Sometimes, in order to lengthen the perforation interval so that the number of perforations can be increased, a slant hole is drilled, or the hole is drilled directionally, so that the drilled hole will not be perpendicular to the water-bearing bed, but will penetrate at an angle with the bedding plane so that a longer length of perforated casing remains inside the aquifer. This will allow a greater number of slots or perforations, and reduce the flow rate at each perforation for the same production rate at the surface. Wells where this can be a problem must begin production very slowly with a gradually increasing production rate, thus producing some of the broken filaments with the water before they have collected into brush piles.

(3) In injection wells, the water being injected must match the water in the aquifer as closely as possible. Any change can cause injection or production problems later in the life of the aquifer. The chemical composition, pH, total dissolved solids, salinity, must match the water in the aquifer or formation damage will occur. The injected water must be free of solid matter and should be free of bacteria. In addition, the temperature of the injected water must not be different from the equilibrium temperature of the target injection stratum, and the injection rate must not be too high. A

higher temperature than the equilibrium temperature can partially dissolve, weaken or swell clay minerals and their crystals, and also will provide a suitable environment for bacteria to grow. Solid foreign matter injected into the aquifer can either cause clay crystals to loosen from the pore walls, or hydraulic fluid flow can cause sufficient force to break off fragile filaments of clay crystals. The partially dissolved and broken filaments can brushpile in pores and pore throats and any sludge produced by growing bacteria or algae can cause blockage thus reducing the flow rate of injected water. The injected water must be free of contaminants, both inorganic and organic, and the injection rate must begin slowly and gradually be increased to the economical injection rate.

formation evaluation: The analysis and interpretation of well logs and other data obtained from scientific instruments run in the well bore for the purpose of determining the fluid content, properties and characteristics and mineralization of earth formations, beds, and strata. See **petrophysical log** and **well log**.

formation pressure: Pore pressure. In aquifers, water pressure.

formation water: Interstitial water. The ionic content of the water in the pores of the rock probably is not the same as that in water that was deposited with the rock originally. Over geological time the ionic content probably has changed numerous times by migration, diffusion, and the dissolution of minerals or by the precipitation of minerals. Compare **connate water**.

fracturing: See **hydraulic fracturing**.

free pipe: Free casing. Pipe or casing in the completed well that is free to vibrate or respond to stress. The undesirable condition in a completed well where the completion operation is defective and cement bond with the casing is faulty. Can allow crossflow or contamination of aquifers behind casing. See **cement bond**, **completion**, **channel**, **channeling**, **crossflow**, and **isolation**.

free water: Water in the pores of the rock that will respond to stimulation and has the freedom to flow or to be produced. See **mobile water**. Compare **movable water**.

fresh: A non-specific term relative to salinity. (1) Fresh water. Very low in salinity. Often used relative to sea water. Not necessarily potable, but can be potable. Compare **sea water.**

(2) Fresh drilling mud. Relative to muds with make-up water designed to produce a filtrate that is fresher than the water in the formation to be drilled.

futile call: A situation in which a junior priority will be permitted to continue to divert in spite of demands by a senior appropriator in the same watershed, because to curtail the junior from diversion would not be effective in producing water for beneficial use for the senior. **CSU.**

gas: A fluid with low density that can completely fill any container. It is compressible, and its volume depends on its pressure and the size of its container.

gas in solution: Under pressure, gases often are dissolved in liquids such as water and crude oil, thus reducing both their **density** and **specific gravity.** When the pressure is reduced the gases can come out of solution. Under some conditions, the released gas can maintain the pressure within the formation.

geofluid: Any fluid, liquid or gas, that occurs naturally in earthen formations, beds, or strata.

geology: The science related to the study of the earth, its history, lithology, depositional and structural history, and development revealed in the rocks, minerals, and fossils.

geophysical well log: Petrophysical well log. A well log that provides a permanent record of the environment of the borehole. See **petrophysical log** and **well log.**

geostatic: Pertains to the weight of the overburden and its contents. Includes rock and all geofluids, both liquids and gases.

geostatic load: At any specific depth of interest, it is the combined weight of the overburden, including its fluid content, that any underlying formation, bed, or stratum is subjected to. Expressed in psi. See also **overburden** and **compaction (2).**

geostatic pressure: A compactive stress. The pressure on any formation, bed, or stratum resulting from the **geostatic load** at a specific depth of interest.

giardia: See **cryptosporidium and giardia**.

gradient: There are many gradients. (1) Relative to water wells and aquifers the gradient usually refers to pressure gradients, hydraulic or hydrostatic. Observe **pressure gradient**, see **hydraulic** and **hydraulic pressure**.

(2) Sometimes used to refer to the slope or inclination of the ground surface with the horizontal.

gravel: Generally, from pebble size to coarse and fine grains of mixed mineral nature.

gravel pack: In a water well. The quantity or mass of fine gravel that sometimes is packed in the annular space between the slots or perforations in the casing and the wall of the formation to help prevent sand production or the free flow of sand from an unconsolidated sand bed during the production of water.

gravity, gravitation: The universal attraction between the centers of material bodies. Newton's Law of gravitation: *Every body in the universe attracts every other body with a force that is directly proportional to the product of the masses of the two bodies and inversely proportional to the square of the distance between their centers*. Every particle of matter attracts every other particle of matter, no matter how far apart their centers, or how much other matter is found in the space that separates them. *Mass* is the amount of matter in a body. The *mass* of a body is its weight measured at a specific point on the earth's surface where the distance to the center of the earth is a fixed constant, and the same constant for all bodies measured relative to earth. The *gravitational force* of a body relative to the earth is the *weight* of the body at its existing location on the surface of the earth. The gravitational force for that body is not constant because of the distance factor to the center of the earth, but mass is considered constant. Example: Man on the surface of the moon where the two masses, that of man and that of the moon, are two constants, but the gravitational force (weight of man)on the moon is considerably smaller than on earth because of the smaller net attractional force of the moon.

gravity drainage: See **drainage (1**).

groundwater, ground water: There is no consistency in literature relative to the words **groundwater** or **ground water.** Probably groundwater is better as an adjective, and ground water is better for a noun. This is water that occupies the interstices of porous and permeable aquifers. Relative to water wells it refers to water, found in and produced from aquifers, that can be put to beneficial use.

groundwater basin: A basin system that contains one or more aquifers, has defined boundaries, and is mappable. The **Denver Basin** is such an example. See **basin.**

Ground Water Commission: A twelve member body created by the legislature, nine of which are appointed by the Governor to carry out and enforce the state statutes, rules, regulations, decisions, orders, and policies of the Commission dealing with designated ground water. **CSU.**

groundwater divide: A ridge in the water table or other potentiometric surface from which ground water moves away in both directions normal to the ridgeline. **GWAC.**

ground water management district: Any district organized for the purpose of consulting with the Ground Water Commission on all designated ground water matters within a particular district. **CSU.**

groundwater mining: Pumping ground water from a basin or aquifer at a rate that exceeds **safe yield**, thereby extracting ground water that had accumulated over a long period of time. See **overdraft. GWAC.**

groundwater reservoir: Observe **aquifer** and **reservoir.** To help understand aquifers, see **drainage**, **drive mechanism**, **pressure gradient**, and **movable water.** Also see **pass-through aquifer.**

groundwater storage: See **injection of potable water for storage purposes.**

grout: A term sometimes used in water-well language to describe the cement, or the cementing process, used during well completion.

growing season: That portion of the year, usually May through October, during which the plants are consuming water and nutrients. **Douglas Co.**

gun, gun perforating: Generally refers to the carrier for the shaped charges, and the holes through the casing and into the formation, made by shaped charges. Bullets can be used, but have been superceded by more effective, designed shaped charges.

GWAC: Ground Water Atlas of Colorado.

gypsum: A common name for the naturally occurring hydrated calcium sulfate. The naturally occurring monoclinic crystalline form of hydrated calcium sulfate ($CaSO_4(H_2O)_2$). Anhydrite is calcium sulfate ($CaSO_4$) existing in the orthorhombic crystalline form. The hydrated gypsum crystal cannot become a crystal of anhydrite (orthorhombic form) in a single dehydration step. Gypsum first must become dissociated in solution before the ions can recrystallize as anhydrite. Compare anhydrite.

hardness: A term that refers to the relative concentrations of calcium ions and magnesium ions in water. See **hard water** and **water analysis**.

hard water: A water solution that contains significant concentrations of ions from calcium and magnesium compounds, carbonates and/or sulfates, particularly calcium bicarbonate ($Ca(HCO_3)_2$).

hard rock: A well cemented, consolidated sedimentary rock.

head: See **hydrostatic head.**

headgate: A physical structure on a reservoir, river or stream through which water is diverted into a ditch.

heaving shale: Shale that becomes hydrated and/or breaks free of the formation by the action of **drilling mud**, the drill bit, and **drill pipe** during the drilling process.

historic use: The documented diversion and use, by a water right holder, of
water in a ditch over a period of years. **Douglas Co.**

hydraulic: Of or pertaining to the mechanics of water to provide pressure and force. In water wells it is the form of pressure that drives water to seek relief in an environment at lower pressure. This is the force that drives water to a well bore. See **hydraulic pressure**, **hydrostatic pressure** and **hydrostatic load.**

hydraulically connected: A condition where two or more aquifers are in communication with each other. This condition can be recognized when the static water levels are nearly the same. See **water level (1)**.

hydraulic conductivity: In 100% water saturated aquifers, hydraulic conductivity is the ease with which water can move through the **interstices** of the aquifer under a specific **pressure gradient.** Applies to either vertical or lateral flow. A part of **Darcy's equation.** If vertical hydraulic conductivity differs from lateral or horizontal hydraulic conductivity, the aquifer is said to be **anisotropic.**

Darcy's linear equation is:

$$q = (kA/\mu) \times (\Delta p / \Delta d)$$

where q = fluid flow rate, k = **absolute permeability** to water, A = cross-sectional area of the cumulative flow paths within the aquifer, μ = **viscosity** of fresh water, Δp = initial pressure difference that provides the energy for ground water to flow across distance Δd. This is an equation that is commonly applied to liquid flow rates in linear lengths of rock. This equation can be rewritten as:

$$q = K(A \times \Delta p / \Delta d)$$

where $K = k/\mu$ is the hydraulic conductivity for the water in a saturated aquifer. This relationship also is the equation for **mobility**, the ease with which any specific geofluid can be moved through a porous medium. In aquifers, it is the ease with which ground water can be moved. Here, hydraulic conductivity is equal to, and the same thing as, **mobility.** The term $\Delta p/\Delta d$ is the **hydraulic pressure gradient.** If Eq.(2) above is solved for K, an alternate equation for hydraulic conductivity is

$$K = (q / A) \times (\Delta d / \Delta p)$$

which is equal to the flow rate per unit cross-sectional area divided by the hydraulic pressure gradient, $\Delta p/\Delta d$.

Transmissivity is defined as K times the net saturated thickness of the aquifer determined from **petrophysical well logs**.

For any specific potentiometric surface measurement, the measurement is site specific. The reference datum level is the elevation of either the perforations or the level where water emerges from the aquifer in a specific water well.

The expression $\Delta p/\Delta d$ is the **pressure gradient** or hydraulic pressure gradient where the initial energy is related to Δp measured between the elevation of the water table at the recharge area and the elevation of the perforations or the level where water emerges from the aquifer. At distance Δd, the distance from the recharge area to the well site, the potentiometric surface has declined and the energy remaining for production, Δp, has declined accordingly. At the producing well site, the reduced Δp is the hydrostatic head that determines both the amount of overpressure of the water in the aquifer and the flow rate. Here, the potentiometric surface has fallen to a lower elevation and is the water level within a static well bore that balances the formation-water pressure. The energy remaining for production, reduced Δp, is measured between the elevation of the new potentiometric surface at the well site and the elevation of the level where water emerges from the aquifer. See **potentiometric surface**, and basic explanation of Darcy's equation at **Darcy's equation**.

hydraulic fracturing: The process of stimulating a formation by creating additional permeability through manmade fractures. A water compatible with the formation is injected into a formation exhibiting *low permeability*. Because the formation has low permeability the injection fluid will have difficulty penetrating the rock and the injection pressure will rise. When the injection pressure exceeds the strength of the rock and overcomes internal stresses, the rock will fracture or split. The fracture must remain open for the stimulation to be successful, therefore, clean sand, aluminum pellets, glass beads, ceramic grains (radioactive or nonradioactive)or other similar materials are pumped into the fracture as propping material, or proppants, to hold the faces of the fracture apart. Hydraulic fracturing is similar in practice to **injection of waste liquids.** Except in the case of hydraulic fracturing, much greater injection pressures are used. In such cases, high pressure injection has caused lubrication of fault interfaces as well as fractures with the result of minor earthquakes. Also see **formation damage.**

The hydraulic liquid usually is water based. Often the water solution will contain appropriate chemicals necessary to increase the flow rate of the produced fluid. The chemicals also might be designed to prevent swelling of clays and to control wettability of the rock. See discussions under **recovery.**

hydraulic gradient: Hydraulic pressure gradient. See equation form as it appears in **Darcy's equation** under **hydraulic conductivity**. See **pressure gradient**, also see **drift.**

hydraulic head: Total pressure head. Non-directional. Sum of both vertical and horizontal components of pressure. Compare **hydrostatic head** and **hydraulic pressure.**

hydraulic pressure: The kind of pressure that exists in the water stream of an aquifer at any specific time. Hydraulic pressure is non-directional, but sometimes is considered to be acting primarily in lateral directions as opposed to vertical directions. Derives its energy from **hydrostatic load.** Expressed in psi.

(1) In aquifers, **backpressure** and **resistance to flow** must be overcome by hydraulic pressure for water production to take place. Regardless of the source of the energy, it is hydraulic pressure that provides sufficient lateral **pressure gradient** to force the formation water into the lower pressure environment of the well bore of a water well.

(2) Pascal's Law states that pressure applied to any part of a free but confined liquid (i.e. water) exerts the same pressure to every other part. In a **confined** aquifer, either an increase in pressure or a decrease in pressure can be transmitted to all other parts of the permeable aquifer system, if they are **hydraulically connected**, subject to **permeability**, until any difference between water pressures reaches equilibrium. As a result, any decrease in water

pressure caused by production at remote wells causes a decrease in water pressure at local wells with the consequent decrease in the life of local water production. See **depleted (2)**.

hydrogen sulfide: The poisonous and corrosive gas of hydrogen and sulfur (H_2S). Occurs naturally in some earth formations.

hydrogeology: The study of ground water and its relationship to geology. Also sometimes known as geohydrology. **GWAC.**

O. E. Meinzer is considered to be the father of hydrogeology. He derived and defined many of the terms used in the study of ground water and hydrogeology (1923). His work preceded any petrophysical well logs and, as a result, he and his followers had no means to describe the characteristics and properties of aquifers by remote, downhole methods. The first petrophysical well log was not performed until Sept. 5, 1927. See **well log** and **petrophysical well log**.

hydrograph: A graph showing stage, flow, velocity, or other characteristics of water with respect to time. A hydrograph commonly shows rate of flow; a groundwater hydrograph shows water level depth and hydrostatic head in a well. **GWAC.**

hydrologic: Pertains to the study of the movement of and distribution of water on the earth. **Douglas Co.**

hydrologic budget, hydrologic balance: Accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, or reservoir; the relationship between evaporation, precipitation, runoff, and the change in water storage, expressed by the hydrologic equation. **GWAC.**

hydrologic cycle: The cycle of water movement from the atmosphere to the earth and back to the atmosphere through **evaporation**, transpiration, condensation, precipitation, **percolation**, runoff, and storage. **CSU.** Renewable water can be renewed only through the hydrologic cycle of water movement of which precipitation is the key to the renewal and sustainability of our water supply.

hydrology: The science and study of underground water resources and the study and treatment of above-ground water, its systems and cycles. Hydrology pertains to the science of surface water and ground water, whereas hydrogeology focuses on ground water.

hydrostatic head: Generic. (1)In a water well, the pressure of a static column of water in a well bore from the water surface to any depth of interest. The water surface can be any depth depending on formation pressure, and is *not necessarily* the **water table.** The hydrostatic head of a **confined aquifer**, for example, is a measurement between the elevations of the **potentiometric surface** and the elevation of the level that water emerges from the aquifer. That pressure for fresh water is 0.433 (psi) per foot of column height. See **potentiometric surface (1).**

(2) In a water well, the pressure of a static column of water in a well bore from the water surface to the depth of water emergence from the aquifer face. The hydrostatic head in the well bore of a water well is the **artesian head.** See **artesian water** and **artesian head.**

(3) In a drilling well, the *hydrostatic pressure* of the **drilling mud** from the *ground surface* to the depth of interest.

hydrostatic load: Sometimes called *hydraulic head*. Specific. The total pressure of a column of formation fluid, usually water, standing between the **water table** and the depth of interest. Expressed in psi (pounds per square inch of area). The load is 0.433 (psi per vertical foot of depth) multiplied by the **specific gravity** of the actual water of interest (a ratio) multiplied by the depth of interest (feet) measured from the water table. The product 0.433 (psi per foot of depth) times the specific gravity of the actual water of interest will be a relatively unvarying hydrostatic **pressure gradient** in water wells. See also **normal pore pressure** and **compaction (2).**

In an aquifer, hydrostatic load, by virtue of its height and weight, provides the energy to transmit pressure from the **water table** to a higher pressure environment at depth where the water then is forced by **hydraulic pressure** to seek relief in the lower pressure environment of the well bore of a water well. Also see **pressure gradient.** See also **artesian head** and **potentiometric surface.**

hydrostatic pressure: One of a number of different forms of **drive**

mechanisms. A static pressure and the vertical component of **hydraulic pressure.** Hydrostatic load generates hydrostatic pressure and is the natural source of the energy in hydraulic pressure. See **aquifer (2)**, **hydrostatic head**, **hydrostatic load**, and **hydraulic pressure (2)**.

igneous rock: Solidified rock formed by cooling and solidifying of **magma** underground or lava on the surface of the ground. Examples are basalt and granite.

illite: A potassium, aluminum silicate. Exhibits the highest radioactivity level of the clays. Density 2.52 g/cm^3. **Diagenetic** or **authigenic** Illite is typified by fragile, leafy, feathery crystals and long delicate fibers adhering to and covering grain surfaces. Such crystals easily can be broken at vigorous production rates or injection rates. See **brushpile.**

immobile water: See **irreducible water.**

impermeable: Impervious to the flow of water or other geofluids. An impermeable rock has extreme resistance to flow. The rock might be porous, but the pores must be connected to provide permeability. Also see **permeability.**

infiltration: (1) Of water on the ground surface, water percolating into the ground from a source such as precipitation or irrigation. See **percolation.**

(2) In drilling wells, it is the penetration of filtrate from drilling mud into the drilled face of porous and permeable strata.

injection of potable water for storage purposes: This is the most complicated of all the operations relative to water treatment and handling. There are many parts to be considered in the injection process for it to be successful and economical.

(1) The highest efficiency is achieved when the water is injected into a reservoir aquifer where the boundaries are finite and measurable, and there is no natural relief for the excess water and resulting reservoir pressure. Under these conditions, the water pressure generated during the injection process will not dissipate, thus ensuring later recovery of a large percentage of the injected water. The lowest efficiency will be found where water is injected into boundless aquifers

containing renewable water, and where the excess water and water pressure generated during the injection process will divert renewal water away from the region influenced by the injection well, and the excess pressure will find natural relief and will dissipate over time. Dissipation of the excess water pressure will turn the water storage operation into an unnatural recharge or augmentation operation where the injected water becomes available in various degrees to all other wells producing water from the same aquifer, and at its worst, a water disposal operation. See **formation damage.**

(2) When water is injected into an aquifer that is overlain by the aerated zone, the injection pressure might not rise appreciably and a clean, clay-free aquifer might take water freely, and the storage operation will be a put-and-take operation over the short term. Over the long term any excess pressure from the injection process will find relief in the aerated zone which is at atmospheric pressure. This will turn the storage operation into an augmentation or recharge operation, increasing the life of the aquifer for all wells producing from the same aquifer.

If the injection into an unconfined aquifer causes the water table to rise, the injected water is being stored. If there appears to be no change in the water table after injection, the injected water is being disposed of. In this case, the quantity of water recovered in later production probably would be nearly the same whether or not injection took place. Also see **formation damage.**

The changes in water pressure in any case can be monitored under static conditions in the injection well or **monitoring wells** by measurements of the **potentiometric surface.**

injection of waste liquids for disposal purposes: There are many parts to be considered in the waste disposal process for it to be successful and economical. This is the most complicated of the injection operations from the standpoint of well completion and zonal isolation. The efficiencies are the reverse of the water storage operation. The highest efficiency is attained in continuous and boundless strata where injection pressure does not build up the pore pressure within the formation, but dissipates freely. The poorest efficiency is observed in zones with low permeability and poor relief, where pore pressures built up in the formation become increasingly difficult to overcome and do not dissipate rapidly. In such cases, injection has caused possible **fracturing**, lubrication of fault interfaces, and mini earthquakes. Also see **formation damage** and **hydraulic fracturing**.

in place: Relative to aquifers, it refers to all molecular water that occupies the pores in the bed, stratum, gravel, sand, or rock whether before or after production. Includes both **irreducible** and **mobile water**. See **depleted (2)**.

InSAR: Interferometric Synthetic Aperture Radar. See under **subsidence (1)**.

instream flow: The amount of water necessary to maintain flowing streams to support marine life or other activity.

instream use: The use of water for beneficial purposes that does not require its withdrawal or diversion from its natural water course.

in situ: In place at its natural location, at existing physical and chemical conditions within the formation.

interbasin transfer: The physical transfer of water from one watershed to another. **GWAC**.

interbedded: Said of beds lying between or alternating with others of different character; especially said of rock material or sediments laid down in sequence between other beds, such as sands and gravels. **NSSH**.

interface: Usually, the surface of contact between two unlike materials. The contact surface between air and water, water and oil, sand and carbonate, erosional surface at an unconformity.

Interferometric Synthetic Aperture Radar: InSAR. See under **subsidence (1)**.

intermediate casing string: One or more protective casing strings sometimes set between the **surface casing** and the **production casing** in order to protect portions of the formation that are sensitive to **drilling mud** chemicals and drilling mud pressures in order to prevent **lost circulation**; or, in formations exhibiting **overpressure**, to prevent collapse of the borehole opposite **plastic shale** or to prevent blowouts of oil or gas from permeable hydrocarbon-bearing beds.

intermittent flow: Recurrent. Periodic. Usually, seasonal flow.

interstitial water: Formation water. The water that occupies space within the interstices and pores of rock, regardless of the water's source or origin. See **formation water** and compare **connate water**.

interstices: The spaces between the grains of **sedimentary** rock.

intrusive rock: Igneous rock that has been formed from **magma** forced into openings between older rock, and then solidified before reaching the ground surface. See **igneous rock**.

invaded zone: The permeable zone surrounding the drilled hole where mud filtrate, under the pressure of drilling mud, penetrates and displaces formation water in individual beds or strata. The efficiency and radial depth of displacement can vary depending on the spurt loss and the permeability of the filter cake. The flushed zone is that part of the invaded zone where the displacement of formation water has been most efficient. Also see **flushed zone**.

invasion diameter: See **diameter of invasion**.

ions: In water. When acids, bases, or salts are dissolved in water solutions, they break up into charged particles called ions. These particles are atoms or groups of atoms. The metal atoms are positively charged because they give up electrons, and non-metals and their clusters, called radicals, become negatively charged because they accept electrons. The solution is electrically neutral because of the equally balanced charges. Positively charged ions are called cations, negatively charged ions are called anions.

iron bacteria: Microorganisms that feed on iron in the water or on the pipe. They may appear as a slimy rust-colored coating on the interior surface of a toilet flush tank or as a glob of gelatinous material in the water. **CSU**.

irreducible water: In aquifers, it represents both the immobile water residing within fine pores and other fine interstices, and the water residing on the *surfaces* of all grains and particles as a result of the respective forces of **capillarity** (**wettability**, adhesion), **buoyancy**, **gravity**, **surface tension**

(cohesion), and **evaporation.** Capillarity, grain surface wettability, and buoyancy are opposed by gravity, surface tension, and evaporation. The *in situ* quantity of irreducible water residing in *water-wet* soils, gravels, sands and other rock materials is directly related to the superior forces of capillarity, wettability, adhesion, and buoyancy, and inversely related to the inferior forces of gravity and evaporation. The greater the combined grain and particle *surface area*, capillarity, and buoyant force, the greater will be the volume of irreducible water. Irreducible water is immobile and part of water **in place** and cannot be made to move while under **in situ** conditions; and, therefore, is not producible. Irreducible water is expressed as a fraction or percentage of porosity. Compare **specific retention.** See **buoyancy**, **capillarity**, **surface tension**, **recovery**, and compare **mobile water.**

The in situ value of irreducible water saturation can be quite different from that determined from the extracted rock sample taken from a different environment or examined in a different environment. The determination of the correct amount of irreducible water is important in determining the **recovery factor.**

irrigation: The application of water to crops, lawns and gardens by artificial means to supplement natural precipitation. Water can be applied by sprinkling, flooding, or dripping. **Douglas Co.**

irrigation district: A legal entity created by statute in order to develop large irrigation projects. **CSU.**

irrigation efficiency: The ratio of the volume of water required for a specific beneficial use divided by the volume of water delivered. It is commonly interpreted as the volume of water stored in the soil for evapotranspiration compared to the volume of water delivered, but may be defined and used in different ways. **Douglas Co.**

irrigation water requirement: The quantity of water, exclusive of effective precipitation, that is required for various beneficial uses. **Douglas Co.**

irrigation year: The irrigation year for the purposes of recording annual diversions of water for irrigation in Colorado begins November 1 and ends on October 31 of each year. **CSU.**

isolation: (1) Related to the effectiveness of the completion of a water well to prevent communication inside the borehole. It is the quality or degree that an aquifer has been cemented, or grouted, to prevent pressure depletion in the aquifer and/or water from crossflowing from the aquifer to another part of the well bore, or to prevent the contamination of the aquifer from crossflow from another aquifer or from the well bore. See **thief zone**, **thief level**, and **back pressure.**

(2)Also see **lens** for isolated **sedimentary** deposits that form **reservoirs** .

isotopes: Atoms of a single element which have differing masses. Isotopes are either stable or unstable (radioactive). Radioisotopes emit particulate (alpha, beta) or electromagnetic (gamma) radiation as they transform or decay into stable isotopes. Daughter products produced by primary disintegration or irradiation are isotopes. **SPWLA.**

junior right, junior appropriator right: A water right that is recorded after older, prior, superior rights.

junk: Any foreign debris, equipment parts, or tool that has fallen into the drilled hole.

kaolinite: An aluminum silicate. Exhibits the lowest radioactivity level of the clays. Density 2.41 g/cm^3. **Diagenetic** or **authigenic** kaolinite is found as face-to-face stacking of leaves or plates in booklets of crystals adhering to and covering grain surfaces.

lacustrine: Pertaining to or formed in a lake or lakes. **GWAC.**

lagoon: A shallow stretch of salt or brackish water, partly or completely separated from a sea or lake by an offshore reef, barrier island, sandbank or spit. **NSSH.**

lake: An inland body of permanently standing water fresh or saline, occupying a depression on the earth's surface, generally of appreciable size and too deep to permit vegetation to take root completely across the expanse of water. **NSSH.**

lamina: The thinnest recognizable layer of original deposition in a sediment or sedimentary rock, differing from other layers in color, composition, or particle size. Several laminae constitute a bed. **NSSH.**

Langelier Index: L.I. A measure of balance in the water of the pH with presence of calcium carbonate. A negative index value (under saturation of calcium carbonate) will result in greater corrosivity; a positive index value (over saturation of calcium carbonate) will result in precipitation of the element, accumulating calcium on water fixtures, etc. **CSU.**

Laramie-Fox Hills aquifer: The lowermost of the Denver Basin Aquifers, which includes fine-grained and medium-grained sandstone. Colorado Division of Water Resources.

lateral: (1)A minor ditch used to direct water onto the land, headgating off the main ditch. A ditch may have many laterals depending on the amount of acreage irrigated, the slope of the land, and the rate of seepage losses. **Douglas Co.**

(2) A direction. More or less horizontal direction.

leaching: The process by which materials such as nutrients or pollutants are dissolved and penetrate deeper into the soil by percolation.

lens, lenticular: A porous, usually permeable **sedimentary** deposit *completely* surrounded and isolated by impervious sediment, beds or strata. A lens or lenticular stratum pinches out in all directions and is completely isolated, and is a singular pressure system within itself. Relative to **aquifers**, this would be a completely **confined aquifer** having no pressure communication with any other, where the quantity of water is finite and water **renewal** cannot take place. Also see **aquifer (3)** and **abnormal pore pressure**.

limestone: (1) A mineral, calcium carbonate($Ca(CO_3)$).

(2) A sedimentary rock consisting primarily of the mineral, calcium carbonate.

liquid: A fluid. The state of the fluid where it can take the shape of its container, but its volume is independent of the size of its container. Most liquids are nearly incompressible depending on gases dissolved in the liquid.

lithification: The conversion of unconsolidated sediment into a cohesive and solid rock, involving processes such as cementation, compaction, desiccation, crystallization, recrystallization, and compression. It may occur concurrently with, shortly after, or long after deposition. **NSSH.**

lithology: (1) Refers to the pattern, mineralogy and physical character of sequential beds and strata.

(2) The study of rocks.

lithostatic load: The net weight of the rock framework or structure from the depth of interest to the ground surface, exclusive of water or any other fluid contained in the pores. Expressed in psi. Compare **hydrostatic load** and **geostatic load**. See **compaction (2)**.

loess: Material transported and deposited by wind and consisting predominantly of silt-size particles. Commonly a loess deposit thins and the mean-particle size decreases as distance from the source area increases. Loess sources are dominantly from either glacial meltwaters or from non-glacial, arid environments, such as deserts. **NSSH.**

log: (1) To log a well for the purpose of making a permanent record.

(2) A permanent record of information pertaining to the environment of a well bore. Obtained from downhole scientific instruments. See **petrophysical log** and **well log.**

logging: Pertains to the running of scientific instruments downhole in a well bore for the purpose of obtaining records for analysis. Also see **well log.**

loss: The difference between the amount of water that actually is delivered and put to beneficial use and the amount of water that was physically diverted. On the ground surface, such losses usually are due to seepage and evaporation during transport or storage.

lost circulation: The undesirable condition where the drilling mud, conditioned to have a pressure greater than the pressure within an aquifer, and having a high water loss at the same time, penetrates freely into the formation and becomes lost. This failure is evidenced by the loss of mud returns to the surface. Not only does this halt the drilling process, but it might contaminate any aquifer where it occurs and might cause formation damage. See **formation damage (1)**.

magma: Molten rock below the surface of the ground.

major dissolved constituents: In water. The greatest proportion of dissolved constituents in water are calcium, magnesium, calcium bicarbonate, chloride, sulfate, and silica, although nitrate can be a major constituent. **GWAC.**

marine deposit: Sediments (predominantly sands, silts and clays) of marine origin, laid down in the waters of an ocean. **NSSH.** Also includes carbonates.

marl: A generic term loosely applied to a variety of materials, most of which occur as an earthy, unconsolidated deposit consisting chiefly of an intimate mixture of clay and calcium carbonate formed commonly by the chemical action of algae mats and organic detritus, specifically an earthy material containing predominantly clay and calcium carbonate mud; formed primarily under freshwater lacustrine conditions, but varieties associated with more saline environments and higher carbonate contents also occur. **NSSH.**

mass: See **gravity**.

matrix: (1) The solid matter of rock, the framework, that surrounds the pores.

(2) The finer, natural material that surrounds imbedded fossils, stones, pebbles, crystals or other features of the rock.

maximum contaminant level: (MCL) Maximum level of a contaminant allowed in water by Federal law, based on health effects and currently available treatment methods. **GWAC.**

metamorphic rock: See **rock (3)**.

meteoric precipitation, meteoric water: Water derived from the atmosphere. Rain, snow.

methane: Methane is a natural hydrocarbon gas that is flammable and explosive in certain concentrations. It is produced either by bacteria or by geologic processes involving heat and pressure. **COGCC**. See **biogenic methane** and **thermogenic**

methane, also **flaming water**.

microannulus: A defect in the quality of the cement bond caused when the casing is subjected to excessive pressure and the cement sheath surrounding the casing is forced to expand along with expansion of the casing. When the excess pressure inside the casing is relieved the casing contracts leaving a microannulus or defect in the cement bond to the casing. This defect can degrade into a channel. See **cement bond, channel,** and **channeling.**

mineral: A naturally occurring chemical element or compound having distinguishing crystalline structure.

minimum streamflow requirement: Water right decreed to the Colorado Water Conservation Board requiring that a set amount of water be maintained in a water course for the purpose of reasonably maintaining the environment. **CSU.**

manmade process: Any process devised by man and performed by mechanical or chemical means, in contrast to any process performed by nature.

mobile water: In aquifers, in contrast with **irreducible water,** mobile water represents only the water that is static, but can respond to stimulation and has the freedom to move. Sometimes referred to as *free water*. It is part of water **in place** until sufficient force is applied to move it. Compare **irreducible water** and **movable water.** See **in place** and **depleted.**

mobility: The ease with which any specific fluid can be moved through a porous medium for any specific pressure gradient. In aquifers, it is a measurement of the ease with which ground water can be moved in an aquifer. The expression is k/μ where k is the **absolute permeability** to water in the aquifer, and is **effective permeability** where water exists in the presence of another fluid; and μ is the **viscosity** of water. Mobility and **hydraulic conductivity** are the same. See **Darcy's equation** under **hydraulic conductivity** where mobility is developed.

monitoring well: Observation well. A non-producing well that is used primarily for taking periodic static water-level depth measurements and for taking water samples for comparisons and for water quality control. Observation wells are not only used for monitoring conditions in an aquifer, but also are used for monitoring changes in the levels of contamination and pollution over time. See **artesian water**, **biochemical oxygen demand**, **water analysis**, **pH** and **potentiometric surface**.

The static water-level depth in a monitoring well is the depth that **artesian water** rises in the well bore. The water surface from which the **artesian head** is measured is not necessarily the same as a water level in the aquifer. There might be no such corresponding water level in the aquifer.

montmorillonite: smectitite montmorillonite. A calcium, sodium, magnesium, iron, aluminum silicate. Exhibits an intermediate radioactivity level for the clays. A water sensitive, swelling clay. Density 2.41 g/cm^3. **Diagenetic** or **authigenic** montmorillonite is typified by its web-like morphology. Authigenic montmorillonite, same morphology as diagenetic montmorillonite, has a noncrystalline cellular, honeycomb structure that adheres from pore wall to pore wall that causes visible pore bridging and pore throat plugging.

moraine: In glacial geology. A mound, ridge, or other topographically distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited primarily by the direct action of glacier ice, in a variety of land forms. **NSSH**.

movable water: In aquifers, it represents only the water that has the freedom to move, but is dynamic and has been made to move under the force of a **drive mechanism**. It is water in a state of motion, or water that has been produced. For this water to be movable, it must be subjected to sufficient force to shear the junction between **mobile** and **irreducible waters** and to overcome both the **resistance to flow** and **back pressure**. See **in place**. Compare **depleted**.

mud: See **drilling mud**.

mud cake: The precipitate of mud solids that are filtered from the **drilling mud** by the drilled face of a porous and permeable formation. The presence of mud cake protects the drilled formation face and, depending on the water loss quality of the mud, inhibits further invasion of filtrate into the formation. In the laboratory, it is *filter cake*.

mud density: The density of drilling mud usually expressed in pounds per gallon or pounds per cubic foot. The density of the drilling mud should be designed to counterbalance the hydraulic pressure within the formation.

mud filtrate: The effluent from a **drilling mud** that penetrates the aquifer or other permeable formation after leaving a precipitate of mud solids on the face of the drilled formation. See also **mud cake.**

mud pit: A containment created to capture the drilling mud that returns to the surface during the well drilling operation. The mud then is available for conditioning and is cycled into the drill pipe and used again and again.

mud weight: A misnomer. See **mud density.**

municipal water system: The network of pipes, pumps, and storage and treatment facilities designed to deliver potable water to homes, schools, businesses, and other users in a city or town and to remove and to treat waste materials. **CSU.**

National Environmental Policy Act: NEPA. Federal law enacted to ensure the integration of natural and social sciences and environmental design in planning and decision-making for federal projects or projects on federal lands. **CSU.**

National Pollution Discharge Elimination System: NPDES. Description taken from a section of the Federal Clean Water Act. NPDES is the mechanism for applying effluent standards, water quality standards, and monitoring requirements. EPA is authorized to issue a permit to any applicant whose discharge meets federal requirements. **Douglas Co.**

National Pollution Discharge Elimination System (NPDES) Permit: A permit required under Section 401 of the Clean Water Act regulating discharge of pollutants into the nation's waterways. **CSU.**

natural: Describes a product of nature. Not reclaimed, not reused. Innate, untreated, not manmade.

natural recharge: A renewal process. Replenishment of water to an aquifer through a recharge area by natural means such as from meteoric precipitation, lakes, rivers or streams. Part of the **hydrologic cycle.**

natural stream: Relative to ground water. A natural stream's waters refers to the migratory waters in aquifers. See **stream.**

native waters: Surface and underground waters naturally occurring in a watershed. **CSU.**

net sand thickness: The net accumulated thickness of sand of a specific quality found within the total thickness of a formation of mixed lithology.

new: Relative to water, natural, not reused, not reclaimed.

non-consumptive use: Water drawn for use that is not consumed, such as hydroelectric power generation, recreation, etc.

non-exempt use: Any recognized beneficial use of water that is administered under the priority system. **CSU.**

non-exempt well: Most non-exempt wells require an augmentation plan. Most wells on single-home residential properties are exempt and do not require an augmentation plan. Water systems on multi-home subdivisions often are non-exempt and require an augmentation plan. **CSU.**

non-native waters: Water imported or not originally connected hydrologically to a watershed or drainage basin physically or by statute; nontributary ground water and transmountain water are non-native. **CSU.**

nonrenewable water: A water source that is not and cannot be replenished through the **hydrologic cycle** or by any natural means. This water is usually considered to be finite.

nontributary ground water: Relative to the Denver Basin, it is ground water that when pumped *will not*, within 100 years, affect the flow of any natural stream by greater than one-tenth of one percent of the annual pumping volume. This is a *nonrenewable* water supply. **Douglas Co.** Also see **aquifer.**

nonpoint source pollution: Pollution coming from a wide, non-specific source such as runoff from cities, farms, forest land. **CSU.**

normal pore pressure: The normal pore pressure is the hydrostatic pressure exerted by a column of formation water (or any and all other geofluids contained in the **overburden**)from the depth of the **water table** to the depth of interest. Normal pore pressure exhibits a normal pore pressure gradient. Formation water is found at some level of saturation in all formations that have porosity. The formation water communicates vertically in all sedimentary formations over the span of geological time. This is what allows normal pore pressure to exist in all formations except where **abnormal pore pressure** is found. Most rocks considered to be impermeable over the human time span exhibit permeability over geologic time, and the formation waters and their pressures are communicable. The timeless communication of fluids and their pressures allows an uninterrupted pressure gradient to exist and to be recognized and be measured in sedimentary formations in wells at virtually all depths presently drilled.

When **overpressure** has been exhausted, normal pore pressure remains in the formation fluids. But, normal pressure contributes very little to the recovery process for any geofluid because the drainage mechanism or mechanism to drive fluid into the well bore has decreased significantly or has diminished to nothing. Under this condition, there is very little fluid of any kind to replace potentially producible fluid. That is why secondary recovery methods are employed. See **recovery**, **drainage**, **normal pore pressure gradient** and compare **abnormal pore pressure**.

normal pore pressure gradient: (1) The rate of change in the normal pore pressure per unit of depth. The normal pore pressure gradient for water is 0.433 (psi per foot) times the specific gravity (a ratio) of the water of interest.

(2) A petrophysical curve showing any porosity-related well-log-derived parameter versus formation depth, from which pressure can be inferred or calculated. Departures from the normal pore pressure gradient curve, suggesting higher porosities, usually indicate the presence of overpressure in the formation. Any overpressure decreases the rate of compaction, thus preserving higher porosities. Preservation of higher porosities under an increasing overburden causes shale to lose rigidity and become **plastic shale**. These departures, in turn, can be interpreted to determine the drilling **mud density** that will be required to completely balance the overpressured zone. Seizing of drill pipe and blowouts, particularly in oil and gas wells, can occur if the

drilling mud in the borehole does not adequately counterbalance the formation pressure. See **abnormal pore pressure**.

not-nontributary ground water: For the Denver Basin, it is waters that, when pumped, *will*, within 100 years, affect the flow of a natural stream by greater than one-tenth of one percent of the annual pumping volume. Because the pumping of not-nontributary water will cause an impact to the surface stream system, an adjudicated plan for **augmentation** is required prior to the use of not-nontributary ground water from the Denver Basin aquifers. This is a **nonrenewable water** supply. **Douglas Co.**

NSSH: National Soil Survey Handbook of the Natural Resources Conservation Service, U.S. Department of Agriculture.

observation well: See **monitoring well**.

open hole: The drilled hole before casing is set in place, or that part of the hole that is not cased.

original right: The first right awarded to a ditch or storage structure. **Douglas Co.**

organic materials: Unconsolidated sediments or deposits in which carbon is an essential, substantial component. Ultimately, these deposits can become peat, coal, kerogen.

outcrop: Of an aquifer. That part of the aquifer at the surface of the ground that is exposed to the atmosphere, lakes, rivers, and streams. The outcrop either escaped burial or was uncovered at the ground surface. This part of the aquifer has been exposed to extreme weathering by wind, rain, freezing, leaching and sun and all other attacks that weathering can bring to bear over a period of thousands if not millions of years. The characteristics and properties of the outcrop, or near surface aquifer, might have characteristics and properties quite different from the buried aquifer. All weathering of the outcrop increases those factors that increase the permeability of surface samples.

over appropriated: An over-appropriated stream is one in which the availability of water is less than the total of the adjudicated water rights on the stream. **Douglas Co.**

overburden: (1) A general term referring to the accumulated total of earth and rock and the fluids that they contain overlying a stratum or depth of interest.

(2) Relative to weight or load in the natural process of compacting earthen materials and rock, it is referred to as **geostatic load**. Expressed in units of psi. See **compaction (2)**.

overdraft: With respect to an aquifer, a withdrawal of water in excess of the natural system's ability to renew that water. The overdraft is equal to the amount of water withdrawn minus the amount of recharge to the aquifer. **Douglas Co.**

overpressure: (1) A fluid state or condition within a formation where the pressure of the formation fluid is greater than normal pore pressure. See **abnormal pore pressure**, **normal pore pressure**, and **normal pressure gradient**.

(2) The amount of pressure that exceeds normal pressure.

packer: An expanding plug or other device used during the completion of a well when it is desired to seal off certain portions of the hole. Packers or plugs are used during cementing operations, acid treatments, and to isolate and seal off aquifers.

parts per million: ppm. Refers to the concentration of ions of solute in solution. Often measured in parts per million, ppm (wt./wt.), but usually measured in units of mg/liter (wt./vol.). A general indicator to the quality of the water. Parts per million differs from mg/liter when the **specific gravity** of the solution differs from the specific gravity of pure water at **standard conditions** of temperature and pressure. See also **total dissolved solids.**

Pascal's Law: Pascal's Law states that pressure applied to any part of a free but confined liquid (e.g. water) exerts the same pressure to every other part. In a **confined** aquifer, either an increase in pressure or a decrease in pressure can be transmitted to all other parts of the permeable aquifer system without regard to differences in elevation, if they are **hydraulically connected**, subject to **permeability**, until any difference between water pressures reaches equilibrium.

pass-through aquifer: An aquifer carrying **renewable water**, where water that is being produced or has been produced is constantly being replenished by natural means. All alluvial aquifers containing renewable waters are pass-through aquifers. The aquifer contains water in a natural, permeable, usually alluvial pathway as the water migrates from one geographical location at one water pressure to another at a different pressure, or to the location of withdrawal. The migrating water stream uses the aquifer as a **conduit** or pipeline to pass from one location to another. See **alluvial** and **stream**, compare **reservoir** and **recovery factor**.

perched water table: A water table of a relatively small groundwater body lying above the general water table, and separated from the underlying aquifer by an **aquiclude. GWAC.**

percolate, percolation: Of liquids. (1) To percolate. To penetrate, under the influence of **gravity**, a natural or manmade porous and permeable medium. Usually in reference to the near surface soil of the ground.

(2) The liquid that percolates.

perennial flow: Year round flow.

perforating, perforations: To put holes or slots through the casing so that fluid can flow from one side of the casing to the other.

permeability: A generic term when used by itself. The ease with which water or other fluids can move through soil or rock. Influenced by many natural factors of rock and fluid. Measured in units of **darcies** or millidarcies. Also see **resistance to flow.**

Permeability is an intrinsic property of the framework of the gravel, sand, or rock constituting the aquifer and is related to the geometry of the voids and surfaces of solid materials. The most obvious influence on permeability is the interconnected void space throughout the aquifer. This is the effective pore space, or effective porosity. The permeability provided by the pores is further influenced by configuration, shape, physical dimensions of the pores and pore throats, tortuosity, continuity, pore isolation, orientation, irregularity, solid-surface roughness, angularity, sphericity, and anisotropy. In addition, the presence of **allogenic** minerals and **authigenic** mineral growths such as quartz or calcite or dolomite or clays, all, contribute to the pathway geometry within the pores. And, the pathways through the rock can be configured further by secondary porosity in all its shapes and forms, such as: dissolution porosity, replacement porosity, fissures, fractures, micro-cracks, and vugs in their various orientations within the rock framework. Finer materials with greater surface areas usually are transported the greatest distance from the source. As a generalization only, and pertaining mostly to aquifers, the permeability decreases with the distance from the source of the sedimentary materials.

(1) **absolute permeability.** The ability of a rock to conduct a given fluid through its interstices when the fluid is at 100% saturation.

(2) **effective permeability.** The ability of a rock to conduct a given fluid through its interstices in the presence of a second fluid immiscible with the first. Because of the mutual interference between the two fluids, the *effective* permeability to water, for example, in the presence of a second fluid, is less than the *absolute* permeability to water.

(3) **relative permeability.** The ratio of the *effective* permeability to a given fluid at partial saturation to the *absolute* permeability to the same fluid at 100% saturation. A measure of efficiency. The ratio varies between 0.0 and 1.0, where 1.0 is for a given fluid at 100% saturation. In the presence of two immiscible fluids, and because of the mutual interference between the two fluids, the sum of their respective *relative* permeabilities can never reach 1.0. A ratio, no units.

petrophysical log, petrophysical well log: A well log record, analog or digital. There are many different kinds of petrophysical well logs, each displaying a specific scientific measurement in the realm of chemistry or physics taken over the formations penetrated by the drill bit, from the ground surface to the deepest depth drilled. A petrophysical well log provides a permanent record of the environment of the borehole. See **well log** for more detailed information

pH: A term representing the hydrogen ion concentration in water solutions.

This term is a measure of either acidity or alkalinity of water solutions. A neutral water solution has a pH of 7. A pH lower than 7 is acidic, and that above 7 is basic or alkaline. A pH lower than 7 can be corrosive to copper pipes in homes and businesses. Also see **Langelier Index**.

phreatic, phreatic zone: Pertains to the water-saturated zone underlying the **water table**. Overlain by the **aerated zone**.

piezometer: A borehole or standpipe in the earth extended below the depth of interest for the observation and measurement of the hydrostatic water level. The standpipe has an opening at or near the bottom to allow water to rise to the level that balances the pressure in the aquifer. The static water level is the potentiometric surface whether the standpipe is in an unconfined or confined aquifer. Piezometric pressure is potentiometric pressure. See **potentiometric pressure**.

plastic shale: Shale that contains a large amount of water and lacks rigidity. Plastic shale supporting a heavy **geostatic load** can find relief by squeezing into a drilled hole. The pressure exerted by plastic shale must be counterbalanced by that of the drilling mud, or the drill pipe can be seized and the hole lost.

point of diversion: A specifically named location where water is removed from a body of water. **CSU**.

point source pollution: Pollution coming from a single identifiable source such as discharge pipes from a commercial enterprise, sewers, private and municipal waste treatment plants, feedlots, golf courses, dumps for garbage or contents from septic tanks, faulty completions or abandonments of wells drilled for oil and gas, uranium or other minerals used for exploration or production, or any other concentrations of organic or inorganic waste, or means of pollutant discharge. Also see **soil vapor intrusion**.

pollutants: Contaminants. Any introduced gas, liquid, solid, inorganic or organic matter, or living microorganisms that makes a resource unfit for a specific purpose.

pore pressure: Pressure exhibited by the fluid in the pores of rock. Formation pressure. In aquifers, it is water pressure. See also **hydraulic pressure**, **normal pore pressure**, and **abnormal pore pressure**.

porosity: Generic. The fraction or percentage of void space in a unit of volume of a rock.

porosity feet: Can be the product of the average porosity and number of feet within a specific thickness of formation from which the porosities were measured. Or can be the sum of accumulated porosities over a selected net thickness within a formation.

porous: Pertains to soil or rock with open spaces or void spaces between the particles and grains of the rock. Sometimes intergranular voids, sometimes voids in fractures, sometimes voids created by dissolved solids. Often interconnected, creating **permeability** and pathways for water (and other natural fluids) to migrate through the host rock.

potable water: Water safe for human consumption. Water suitable for drinking and cooking purposes.

potentiometric surface: (1) It is a real or imaginary water-level surface or web that spreads across the aquifer that corresponds to water levels measured in well bores of strategic static water wells and **monitoring wells.** Usually these are measurements of **artesian water** levels. The artesian water level reflects the artesian head, or hydrostatic head. This, in turn, is a measure of the amount of **abnormal pore pressure** (overpressure). The water levels in the well bores from which these measurements are taken are not necessarily the same as water levels in the aquifers, or **formation.** There might be no such corresponding water level in the aquifers because in **confined aquifers** there might be no source of air for an air-water interface to be present. The static water-level in the well bore corresponds with the **hydrostatic head** that balances the formation-water pressure at the drilled face of the aquifer.

The potentiometric surface is the **water table** in **unconfined aquifers.** In **confined aquifers**, where no water table exists, the potentiometric surface is considered to be an imaginary **water table.** The height of the potentiometric surface above the level that water emerges from the aquifer describes the potential for water production. If the actual static water level in the monitoring well or static water well falls below the upper boundary of the aquifer the hydrostatic head will have dissipated and little or no water production can be expected by this means of pressure. Water saturation still remains at 100%, but the remaining water must be removed by forceful **drainage** methods. If the elevation of the surface of the ground should fall below the elevation of the potentiometric surface, ponds, lakes, springs, and water flows will be found. The warping downward of the interface between water and air in a **cone of depression** is a depression of the potentiometric surface. See **cone**. See also **abnormal pore pressure(1)** and **drainage**.

For any specific potentiometric surface measurement, the measurement is site specific. The reference datum level is the elevation of the level that water emerges from the aquifer in a specific water well.

The expression $\Delta p/\Delta d$ in Darcy's equation is the **pressure gradient** or hydraulic pressure gradient where the initial energy is related to Δp measured between the elevation of the water table at the recharge area (outcrop) and the elevation of the perforations or the level where water emerges from the aquifer. At distance Δd, the distance from the recharge area to the well site, the potentiometric surface has declined and the energy remaining for production, Δp, has declined accordingly. At the producing well site, Δp is the hydrostatic head that determines the excess water pressure in the aquifer. Here, the potentiometric surface has fallen to a lower elevation and is the level inside a static well bore that balances the formation-water pressure. The energy remaining for production, Δp, is measured between the elevation of the new potentiometric surface at the well site and the elevation of the level where water emerges from the aquifer. See the basic explanation of Darcy's equation at **Darcy's equation**.

For a detailed discussion of **Darcy's equation** relative to the potentiometric surface go to **hydraulic conductivity**.

The potentiometric surface was first defined by O. E. Meinzer in 1923. Meinzer is considered to be the father of **hydrogeolog**y.

(2) Conversion of **confined aquifers** to **unconfined aquifers**. The potentiometric surface at or near the elevated **recharge area** of a confined aquifer will drop as long as water consumption exceeds recharge. Precipitation and other ground-surface water is the source of renewal of water throughout the recharge area. Below the aerated zone in the recharge area lies the water table created over geologic time. As the demand grows for

ground water produced from the confined aquifer, a pressure decline takes place and the water table falls correspondingly. The drop in the water table might reach the depth where it enters the confined portion of the aquifer. It is possible then for air at atmospheric pressure to enter the former confined portion of the aquifer and cause it to become unconfined. Thus, conversion begins and production will resume.

(3) An immediate result of the conversion of confined aquifers is the loss of former actively producing water wells in and near the recharge area. These wells will have ceased production due to the drop in the elevation of the water table.

Another consequence of this conversion that is not first recognized is: As the water table falls, so does the potentiometric surface throughout all of the aquifer fed from this recharge area. The consequence of this continuing downward adjustment of the water table is that the potential for water production at all dependent wells will decrease right along with the falling water table at the recharge area. In Darcy's equation, the fall in the potentiometric surface results from a reduction of the initial Δp. Every well in the aquifer ultimately will experience this reduction in formation pressure as the potentiometric surface adjusts to the falling water table at the recharge area. Some wells at remote locations from the recharge area will cease production earlier than others depending on the absolute permeability to water, shown as symbol k, in Darcy's equation, and their elevations at the depth level of water production. These wells often will experience a decrease in the value of k as distance from the source of the **sedimentary** materials increases. Near the source of the sedimentary materials, larger particles and grains are the first to fall out of blowing wind and moving water. Finer particles and grains are carried farther from the source by wind or water. Smaller grains and particles exhibit larger surface areas resulting in lower permeabilities in their deposits and larger amounts of **irreducible water.** As distance increases, This will compound the decrease in the **hydrostatic head** at the producing well site.

Also, relative to depleting **confined aquifers**, see the discussion on flooding by the injection of compressed air under **drainage(2)** and **recovery(2)**.

precipitation: (1) Meteoric water. Water in any form derived naturally from the atmosphere. Rain, snow.

(2) From water solutions. In a saturated or nearly saturated solution containing a uniform mixture of a dissolved substance (a *solute*), if conditions are changed slightly the solution can become over saturated and the solute will drop out of solution by precipitation or crystallization until the solution is no longer over saturated. See **authigenic.**

(3) From sea water. The process whereby materials, substances, secretions, siliceous skeletons of diatoms, or other organic or inorganic forms of matter settle out of water by virtue of their weight.

preservation: The protection from destruction, depletion, or pollution of any natural resource for future use. The act of setting aside or saving a natural resource. This involves limiting the use, waste, exploitation, and pollution of a resource. Preservation is supported by any conservation means including the reuse through reclamation or other treatment of a used resource. Also see **conservation** and **environmental concerns.**

pressure: The force per unit area applied to a surface or cross section. The hydraulic pressure that drives water to the well bore.

pressure drop: The loss of pressure, caused by the **resistance to flow**, measured between one location and another. Also, the difference between one **potentiometric surface** to another at lower pressure.

pressure gradient: (1) Generally considered to be the variable **hydraulic pressure** gradient because the **hydrostatic pressure** gradient for water is fixed at 0.433 (psi per foot of height) times the **specific gravity** of the water of interest. The gradient is a measure of the rate of change in the difference in water pressure from one location, level, or depth to another. In producing aquifers, the rate of change is directly related to the hydraulic pressure required to *drive* water toward and into the well bore. This pressure is directly related to the **drawdown** and the resulting **hydrostatic head** for the water level in the well bore under producing conditions. In producing water from the aquifers, the gradient is influenced by both the hydrostatic head within the water-well casing and the **formation pressure** and the **absolute permeability** to water in the producing part of the aquifer. Without sufficient formation pressure and/or sufficient resulting gradient, neither **resistance to flow** nor **back pressure** will be overcome and water in an aquifer will not flow, but simply will remain as water in place. See **in place**, **pumping process**, and **withdrawal process**.

The highest efficiency for the hydraulic pressure gradient is found opposite those producing aquifers where **drawdown** is least for any specific production rate, regardless of hydraulic pressure in the aquifer. This signifies that the resistance to flow can be overcome easily by whatever formation pressure exists. Also see **drainage area** and **resistance to flow**.

(2) Hydraulic pressure gradient. The change in pressure per unit length within an aquifer. Either horizontal or vertical. See the equation form of hydraulic pressure gradient under **hydraulic conductivity** as it appears in **Darcy's equation**.

pressure tank: Usually a water storage tank equipped with an air bladder maintained under pressure that regulates the water pressure in the house. When the pressure at the tank decreases to a predetermined minimum pressure, the well pump is turned on. When the pressure in the tank reaches a maximum predetermined level, the pump is turned off.

primary recovery: See under **recovery**.

prior appropriation: Doctrine for prioritizing water rights based upon dates of appropriation (first in time, first in right). Common method for allocating water rights in the western United States. **WGAC**.

priority: The relative seniority of a water right as determined by its adjudication date and appropriation date. In some cases, other factors are involved in determining priority. The priority of a water right determines its ability to divert water in relation to other rights during periods of limited supply.

priority date: The date for establishment of a priority is the date of application for the water right.

production: (1) The state of a water well when producing water.

(2) The total volume of water produced from a well, accumulated from the date the well was first put on production, or the total volume of water over a specified time period.

production casing, production string: In the case of water wells, **surface casing** also can serve as the production casing. In the case of oil and gas wells, the production casing always will be steel for strength, and the production casing is run through all intermediate casings, including the surface casing, all the way to the bottom of the drilled hole. The production casing encloses tubing and pump and protects all downhole equipment used for production purposes in completed wells. Running production casing in the drilled hole is part of the **completion** process, and the casing must be properly cemented in place to isolate all permeable zones.

proration: Relative to water, a means for determining equity decreed by a government agency or court.

protection casing, protection string: (1) Sometimes called **conductor pipe** when it is the primary casing set in an oversized borehole for the purpose of preventing the collapse of the hole, or to protect the **aerated zone** and near-surface aquifers from contamination and damage. See **conductor pipe.** Compare **surface casing** and **production casing.**

(2) An **intermediate casing string.** One or more protective casing strings sometimes set between the **surface casing** and the **production casing** in order to protect portions of the formation that are sensitive to **drilling mud** chemicals or drilling mud pressures in order to prevent **lost circulation**; and, in formations exhibiting **overpressure**, to prevent collapse of the borehole opposite **plastic shale** or to prevent blowouts of oil or gas from permeable hydrocarbon-bearing beds.

protection casing: The primary casing set in an oversized borehole for the purpose of preventing the collapse of the hole, or to protect the aerated zone and near surface aquifers from contamination and damage.

pumping process: In a water well, the well pump withdraws water from the well bore, not from the formation. (Side note. The water-well pump cannot draw water to the well bore by *suction*. A vacuum, even if it could be created, cannot drive water to the well bore because a vacuum is neither a source of energy nor a form of force. See **suction.**) The pump does not *draw* water from the aquifer, but reduces the **hydrostatic head** of the water inside the well **casing**, thus reducing the **back pressure** that opposes the flow of water into the well bore. Water that emerges from the aquifer has been *driven* from the aquifer into the well bore, and its **casing**, where the pump forces the water to the surface through **tubing.** Assuming that water enters the well bore faster than it is produced, the height that water can be *lifted* and the rate that water can be produced depends on the *lifting* capacity of the pump. Also see **withdrawal process** and **drainage.**

pumping water level: See **water level (2).**

quartz: The primary composition of sand. Silicon dioxide (SiO_2). Granular quartz can form a porous rock layer or body. Found in **sedimentary** deposits, common in **igneous rock.**

quartzite: Metamorphic sandstone. Also see **rock (3).**

radioactivity: A property of unstable isotopes which undergo spontaneous atomic readjustment with the liberation of particles and/or energy (for example, alpha or beta particles, neutrons, and gamma rays). Alpha and beta emission change the chemical nature of the element involved. The loss of energy will result in the decay or transformation of the unstable isotope into a stable isotope; or transmutation into an isotope of another element, sometimes giving rise to emission of neutrons. Also see **isotopes. SPWLA.**

radius of invasion: The radial depth within a formation that has been penetrated by drilling mud filtrate.

radon, radon gas: A chemically inert, naturally occurring gas produced by the natural radioactive decay of uranium. The heaviest of all known gases. Radon is an invisible, odorless gas at standard conditions of temperature and pressure and is toxic to humans. Radon gas from soil, weathered rock, and ground water volatilizes and decays into radioactive particles. These particles can be transported by dust and rising air and brought to the earth's surface in water wells and springs. If consumed or inhaled, the particles become trapped in lungs or other body tissue. Radioactive energy released from these particles damages cell tissue, increasing the risk of cancer. **CSU.**

raw water: Natural, untreated water.

rebound: Relative to **compaction** and **subsidence.** It is any degree of return of the compacted **clay shales** and aquifers to their former compacted state as existed before subsidence took place.

Complete rebound, as might be brought about by any means, is not likely to occur. During the compaction process, sediments, particularly clay shales, undergo permanent changes that cannot be reversed. See **compaction (2)**. Some seasonal rebound might be observed, but this would have to relate to non-permanent compaction events that occur within aquifer systems. Some seasonal subsidence and rebound due to elasticity of earthen materials has been observed by Jorn Hoffman, et al, *Water Resources Research*, V.37, no.6, 2001. Some seasonal rebound (in the range of 4")also has been observed by **InSAR** measurements in the metropolitan Los Angeles, California area. This is unusual, but can happen when the mineral structure of the aquifer has sufficient elasticity and the difference in height is large between the elevation of the **water table** in the **recharge area** and the depth of the aquifer. See elastic rebound in **bulk modulus(3 and 4)**. Limited hydraulic rebound by increasing pore pressure in aquifers by natural or artificial means, such as injection of water, might be possible, but this can happen only in **confined aquifers** where there can be no pressure relief.

This behavior of producing aquifers and associated clay shales is predicated on the occurrence of compaction resulting from excessive water production and measurable subsidence occurring at the ground surface.

recharge: (1) Natural recharge. To add to or replenish water in an aquifer at its source by natural means. A renewal process. Part of the **hydrologic cycle**.

(2) Unnatural recharge. Augmentation. To add to or replenish any downstream supply by manmade means. A means of returning water to an aquifer after it has been put to beneficial use. A conservation measure, not a renewal process, and not a part of the **hydrologic cycle**.

(3) Unnatural recharge. To add to or replenish the energy to drive water to the well bore by manmade means.

recharge area: See **aquifer recharge area** and **outcrop**.

reclaim: To collect, filter and/or chemically treat water for downstream **reuse** of the same water. A conservation measure to prevent waste.

Reclaimed water must not to be confused with **renewable** water because no new water is added to the original water supply to improve sustainability. Reclaimed water is not new water, it is the same water that entered the stream or system before and has been put to beneficial use at least once. But, after its primary use, the water has been reclaimed through manmade processes for further downstream recycling or beneficial uses. There is no increase in supply. The material balance of the resource remains unchanged. See **effluent (1)** and compare with **renewable water.**

recovery: There are several recovery methods. Some are natural and some are man made. For aquifers, the number is very limited. In oil-and-gas recovery, the number of methods greatly exceeds the number available for aquifers.

1. Primary recovery is the recovery of formation fluids by natural sources of energy. In **unconfined aquifers** the **water table** is the **potentiometric surface.** The water table immediately beneath the overlying **aerated zone** can and often does vary in depth with seasonal fluctuations. The pressure of the water between the water table and the depth where water is produced is a **hydrostatic head** that causes water to rise in the well bore to the depth of the water table. In unconfined aquifers, the natural source of energy is gravity. Gravity always is present. But, for gravity drainage to occur, something must allow formation water to move. In unconfined aquifers, it is air from a growing aerated zone that replaces movable water. In confined aquifers, it is more water from whatever source or means. These will be discussed below. See **potentiometric surface** and **drainage.**

In **confined aquifers** a means occurs when there is positive vertical separation between the level of the **potentiometric surface** at the well site and the level in the aquifer where water emerges. The vertical separation between these two levels produces a hydrostatic head giving rise to **overpressure.** This overpressure causes ground water to rise in the well bore to the level of the **potentiometric surface.** In aquifers this overpressure is called **artesian head** (this can be measured in nearby **monitoring wells**). When the potentiometric surface falls to the level of water emergence, there is insufficient pressure to push water into the well bore above the level of emergence. The natural hydrostatic energy will have dissipated and water production will decrease markedly and perhaps cease for all practical purposes.

There are a number of natural means to maintain overpressure, otherwise called artesian pressure, in the aquifer. Water pressure in the formation can be the result of natural movement of formation water into the environment of the producing well. This movement of water to replace water being produced is called **water drive** and can be the result of decreased water pressure at the well site due to water withdrawal, or it can be related to events occurring at remote locations at higher elevations, particularly at the **recharge area**. Also, formation pressure can be sustained by dissolved gas coming out of solution, and gas-cap expansion.

In aquifers, primary recovery consists of several occurrences, all of which decrease with distance from the source. In aquifers, the natural events acting simultaneously and cumulative, by whatever magnitude are: (a) Recharge at the recharge area. (b) Drainage by gravity from the recharge area to the producing wells where the difference in depth between the potentiometric surface and depth of water emergence from the aquifer constitutes the energy for water production. (c) Water expelled from the aquifer and surrounding clay shales by compaction resulting from the decline in aquifer water pressure due to pumping. (d) Water expansion as a result of the decline in aquifer water pressure. (e) Dissolved gases coming out of solution resulting from the decline in aquifer water pressure. All natural occurrences identified here contribute to overpressure, and decrease the rate of decline of the decreasing pore pressure, often referred to as artesian pressure. Because of these several factors, the rate of recharge at the source is masked by these other factors.

The occurrences listed in the paragraph immediately above are natural drive mechanisms that create overpressures or maintain existing pressures until these actions dissipate. These occurrences constitute means for primary recovery. When the primary recovery has been exhausted, secondary recovery efforts are employed. In aquifers, secondary efforts are extremely limited.

Normal pore pressure that remains in formations after overpressure has been dissipated contributes little to the recovery process because the drainage mechanism or mechanism to drive fluid into the well bore has dissipated or does not exist due to the relatively great distances from the recharge area. Under this condition, there is very little fluid of any kind to replace potentially producible fluid. Observe the effect caused by distance Δd in the rewritten Darcy equation:

$$q = (kA / \mu d) \times \Delta p$$

When primary recovery means are exhausted secondary recovery methods are employed. See **recovery**, **drainage**, **potentiometric surface**, **normal pore pressure**, and **abnormal pore pressure**.

2. Secondary recovery is man made. When no more formation fluid will flow by natural drainage methods, then fluid can be injected into a nearby well bore to increase the pressure within the formation to force the desired fluid to enter the producing well bore. In oil and gas wells, the fluid injected usually is water to displace oil or gas and increase or maintain pressure. This is called a water flood. Other fluids that may be injected might be natural gases. See **flood**.

In aquifers, it is not an option to inject surface water to increase the pressure to drive ground water out of the aquifer. There might be no other fluid that is as cost-effective as air. It is possible to inject air by compressors on the ground surface. The appropriate locations for compressors and appropriate wells for the air injection process must be selected with great care after studying the geology of the aquifer. If not, the injected air might accumulate in the aquifer at water-producing wells causing them to cease production.

3. Tertiary recovery usually is the costly method used to recover as much formation fluid as possible that remains in the rock after secondary recovery operations have been exhausted. Tertiary recovery is not an option in aquifers. These recovery methods might be the injection of chemicals in solution, surface active agents, miscible solvents, or air. In the case of air injection in oil and gas wells, the oil will ignite by spontaneous combustion, thus heating the rock and producing combustion gases at the same time. In an oil reservoir the increased temperatures might reduce the viscosity of oil, and at the same time the gases produced might increase the pressure to drive the oil to the well bore of the oil or gas well. See **drainage**.

recovery factor: The percentage or fraction of the total volume of the resource that can be recovered by applicable recovery means. The recovery factor is a function of and is dependent on the means of **drainage** that takes place or actually can be implemented under in situ conditions. Applies to reservoirs and other forms of resource deposits where the capacity or quantity is a finite, determinable volume. Meaningless when applied to a resource that is renewable, such as water in a **pass-through aquifer**, or where boundaries and volume are indeterminate. See **drainage**, **renewable**, **reservoir**, **recovery**, and **irreducible water**.

recycle: The act of collecting water or any other exhaustible product for
treatment and **reuse**. A conservation measure to prevent waste, not a **renewal** process.

reef: A significant limestone body of rock, sometimes of reservoir quality, formed under water by the skeletal remains and secretions of organisms, particularly corals. It is resistant to sea action and usually rises or stands above surrounding sediments.

relative permeability: See **permeability (3)**.

relief: In porous and permeable aquifers, the equilibration process where water at higher pressure at one location always will seek to reduce the excess pressure through communication with any location where pressure is lower. See **pressure gradient**, **communication**, **hydraulic pressure**, and **conduit**.

renewable: That which can be renewed. Describes the state of an original, natural, usually exhaustible resource that can be replaced, is being replaced, or is being regenerated by natural means, such as by meteoric precipitation, rivers and streams, wind, solar, or geothermal. Water is renewable through the **hydrologic cycle**. Not synonymous with **reusable**. Compare **effluent (1)**.

renewable water: Water originating only from tributary sources such as: meteoric precipitation, rivers, lakes and streams. Alluvial aquifers deriving its water from these sources are annually recharged through the natural means of the **hydrologic cycle**, so that the water supply is sustainable over time. The primary criterion for renewable water is that it is renewed by natural means, i.e. it is not derived from prior **beneficial use** or **consumptive use** of any water supply. Not to be confused with **reusable** or reclaimed water. Compare with **effluent (1)**.

renewal: That which renews. A process by which any resource can be restored by natural means. The rate of depletion of this resource can be lower than, the same as, or greater than the rate of renewal, depending on consumption. See also **hydrologic cycle**. Compare **effluent (1)**.

reservoir: An above ground vessel, impoundment, pond, or lake; or an underground porous and permeable rock body that can entrap water, oil, or gases in a finite, measurable volume that can be filled and emptied of its contents. The basic premise of a reservoir is that it be a closed system with dimensions that can be determined so that volumetric calculations can be performed. Sometimes natural, sometimes manmade. Also see **trap** and **lens**, compare **pass-through aquifer**.

resistance to flow: Relative to water in an aquifer, it is the composite of those factors within the aquifer that decrease **permeability** and oppose the flow of water, such as: decreased porosity, friction, capillarity (adhesion, cohesion), cementation, **tortuosity**, discontinuity, decrease in grain size (increase in grain-surface area), angularity of the grains, efficiency of grain packing, decrease in size of pores and pore throats, increase in mineralization, presence of fines and clays and other pore infill and obstructive materials. Can be overcome only by sufficient **hydraulic pressure** to maintain or force water to flow toward the well bore. See **permeability**, also **Darcy's equation**.

Resume: A monthly publication by the water court of a summary of water rights applications filed in the water court that month. **CSU**.

return flow: The amount of water returning to the water supply after it has been released from the point of use and thus becomes available for reuse.

reusable: Describes a substance that has been used before and has been treated to become usable again. Not synonymous with **renewable**. Reclaimed water is reusable water. See also **reclaim**.

reuse: To use again after manmade reclamation or treatment has taken place. Water sometimes is reclaimed for reuse. A conservation measure to prevent waste. See also **reclaim**.

riparian: Of or pertaining to rivers, streams, lakes and their banks.

rock: A generic term used to refer to earthen formations, beds, or strata without reference to mineral composition, properties, consolidation, or fluid content. Also relative to samples brought to the surface for examination. More specific:

(1) **Sedimentary**. The usual aquifer is sedimentary material. Can be sediment or fragments of source material that have been transported by water and then deposited as river beds and stream beds. Or can be material transported by wind and water to be deposited as sand dunes, beaches and sand bars. Can be unconsolidated or consolidated. Usually has some permeability. Or, it can be solid matter, such as salt or gypsum, that has precipitated from water, or skeletal remains or secretions of organisms precipitated to form limestone. Here, permeability exists in fractures, dissolution porosity and cavities, and karsts.

(2) **Igneous**. Formed from the cooling of **magma** or lava. Usually impermeable except for fractures.

(3) **Metamorphic**. **Igneous** and **sedimentary** rocks that have undergone changes in crystallization as a result of having been buried at depth within the earth and subjected to elevated temperatures and pressures, and different chemical environments.

risk assessment: Evaluation or the potential for exposure to contaminants and the associated hazards. **GWAC.**

rugosity: The degree of roughness and irregularity of the borehole wall.

Safe Drinking Water Act: SDWA. Federal legislation that regulates the treatment of water for human consumption. Requires testing for and elimination of contaminants for the protection of human health. **CSU.**

safe yield: (1) Rate of surface-water diversion or groundwater extraction from a basin for consumptive use over an indefinite period of time that can be maintained without producing negative effects; (2) The annual extraction from a groundwater unit which will not, or does not, produce a negative effect, (3) the attainment and maintenance of a long-term balance between the amount of ground water withdrawn annually and the annual amount of recharge; (4) the maximum quantity of water that can be guaranteed from a reservoir during a critical dry period. **GWAC**.

saline water: Usually considered to contain more than 10,000 ppm of total dissolved solids. See **total dissolved solids**.

salinity: Pertains to the concentration of **ions** in a solution containing dissolved salts.

sand: A **sedimentary** rock, of **igneous** origin, unconsolidated or consolidated, composed of individual grains of silicon dioxide. See **quartz** and **rock (1)**.

sand control: Any means to prevent sand from entering the casing and tubing. See **gravel pack** and **sand production**.

sand count: The net footage of sand strata of specific quality within a formation.

sand production: Production of water from unconsolidated aquifer sands sometimes causes sand to flow into the casing, filling up the casing to the perforations and getting into the downhole equipment, causing obstruction and rapid wear.

sandstone: A sand that has been consolidated to some degree by minerals, that cement the grains together, precipitated from formation water.

sanitary well seal: At the wellhead, the cap at the top of the protective casing to prevent contamination of the well.

saturated, saturation: Generic. (1) Usually thought of as the portion of a rock body that is filled with water. The saturated zone or thickness.

(2) Specific. The degree that a specific **geofluid** occupies the pore volume of a rock. Expressed as a fraction or percent of the available pore space.

saturated thickness: Generic. The thickness of the zone considered to be completely saturated with water. The thickness containing 100 percent water.

scale: Chemical scale. The undesirable mineral deposited, usually from hard water, on or in water handling equipment. Can be found downhole on solid surfaces inside tubing, pipes, slots and perforations, and pump apertures. And, can be found above the ground in or on any equipment used for the purpose of carrying or discharging water. Usually a carbonate of calcium.

sealed reservoir: A natural reservoir containing water or other geofluid, that has finite natural boundaries by being confined within permeability barriers. The barriers can be impermeable rock of the same nature as the reservoir rock, or they can be impervious shale, carbonate beds, or salt that abuts or surrounds the reservoir. See **aquifer (3)** and **lens**.

sea water: Water from the oceans. Sea water contains many different dissolved salts. The equivalent concentration of sea water is 35,000 ppm, and has a specific gravity of about 1.025 g/cm^3.

secondary recovery: See under **recovery**.

sediment: Solid matter, mineral and/or organic, that has been transported from its location of origin by one or more of the depositional environments. Solid matter also might be the skeletal remains and secretions of organisms that have formed in or precipitated from solutions or sea waters. See **depositional environment** and **rock**.

sedimentary: Refers to sediment deposited in any one of the depositional environments: wind, seas, and rivers. Refers to rock types such as sand, shale, limestone, conglomerates, or reworked mineral material. See **depositional environment**.

sedimentary basin: A basin-like geological environment suitable for the deposition of sediments. Sediments are thicker toward the center and thinning toward the perimeter.

secondary porosity: Post depositional void space in rock. Porosity created in the form of, or by, fractures, dissolution of solid materials in sediment, vugs, diagenesis, or shrinkage. Expressed as a fraction or percent of total volume.

Senate Bill 5: SB5. A 1985 Colorado legislative enactment chiefly providing for allocation of non-tributary ground water on the basis of ownership of the overlying land. The SB5 computer program has been used as the uniform standard as the most consistent criteria to quantify water under a property. For each aquifer:

(Volume of Available Water) =
(Area(acres)**)** × **(Thickness**(ft)**)** × **(Specific Yield**(fraction)**).**

This equation is based on the reservoir and recovery-factor concept, and on the science in the State of Colorado, as it was known in 1985. Presently Senate Bill 5 is law and is regulatory until determined otherwise.

Technically, Senate Bill 5 applies only to **reservoirs** which have finite bounds. However, SB5 appears to be based on the premise that conversion of confined aquifers to unconfined aquifers will take place and thus will unlock residual water in the confined aquifer by gravity drainage. See **conversion of confined aquifers to unconfined aquifers** and **coning (3) and (4)**. Also see **aquife**r, **reservoir**, **recovery factor**, **depleted**, **drive mechanism**, **pressure gradient**, **movable water**, **irreducible water**, **capillarity**, **buoyancy**, and **yield**. See also **equity** and **equity determination.**

senior right: A water right that has been established earlier and, therefore, is superior to any subsequent right.

shale, shaly: A descriptive property, not a mineral. A fine grained, thinly laminated or fissile rock formed by the compaction and consolidation of sediment under the weight of the overburden. The sediment consists of appreciable quantities of clay, silt, and mud. A clay shale is a shale wherein the major mineral constituent is clay.

shaped charge: Used in gun perforating operations. A high explosive with a designed, lined cavity to shape the jet used in perforating a casing. The cavity is lined and designed with a material and shape to create proper sized holes and penetrate the formation with the most efficient cavity for the production or injection of fluid.

shut in: The condition or act of shutting down all valves and pumps in a producing water well or injection well. The conditions in the well bore will be static.

shut-in pressure: Must be specific. Pressure at the wellhead, or pressure opposite the producing formation at the depth of interest, at static conditions.

silica: Silicon dioxide (SiO_2). Quartz.

siliceous: Containing abundant silica derivatives or quartz.

silt: Pertains to size. Very small sized grains or particles of quartz and/or clay derivatives.

sink, sinkhole: A depression in the surface of the earth caused by dissolution and/or collapse of rock. A sink is an entry point for water into cave and spring systems. All sinks will carry water into the subsurface. **GWAC.**

slant hole: A hole intentionally drilled at an angle with respect to the vertical. A directional hole with a designed inclination with respect to vertical.

slots: Slices or slots in the casing placed at pre-selected locations and at specific intervals along the casing before it is run into the borehole and set in place.

soft formation: Unconsolidated or poorly consolidated sedimentary rock.

soil vapor intrusion: An intrusion into the indoor air of buildings by toxic gases that have penetrated foundations. The toxic gases might be from natural sources, manmade activity, or from contamination of the soil by volatile chemicals. Usually the expression is used to refer to intrusion by gases that have been released from toxic chemicals that found their way into the soil by an unnatural event, accident or action. Also see **point source pollution.**

solution gas: Usually pertains to oil and gas production. In water production, it is the gas that has been dissolved in the formation water that is released as water pressure is decreased by water production.

source: (1) Of water in an aquifer. The location or origin where natural charging or beginning takes place.

(2) Relative to crossflow, it is the place on the face of an aquifer where water emerges.

special district: A quasi-municipal corporation of the State of Colorado empowered to perform and deliver services to the owners of property located within a legally described boundary. **Douglas Co.**

specific conductance: A measure of the ability of water to conduct an electrical current. The inverse of electrical resistivity. Specific conductance is related to the type and concentration of **ions** in solution and can be used for approximating the dissolved-solids content of the water. See **total dissolved solids.**

specific gravity: Sometimes mistakenly referred to as density. Density is mass per unit volume (mg/liter or g/cm^3). Specific gravity is a ratio of densities and, therefore, has no units.

(1) Of liquids and solids. The ratio of the density of the selected substance at standard conditions of temperature and pressure to the density of pure water at standard conditions of temperature and pressure.

(2) Of gases. The ratio of the density of the selected gas at standard conditions of temperature and pressure to the density of dry air at standard conditions of temperature and pressure.

specific retention: (1) This is the ratio of the volume of water that a given body of rock or soil will hold against the pull of **gravity** to the volume of the body itself. It is usually expressed as a percentage. Compare with **field capacity. GWAC.** Specific retention is a fraction of total volume without regard to the porosity of the aquifer. Compare with **irreducible water.** Also see **drainage.**

(2) Water adhering to the surfaces of all water-wet soils and grains. Compare **in place**, **irreducible water**, and **capillarity.**

specific storage: Volume of water released from or taken into storage per unit volume of the porous medium per unit change in head. It is the three-dimensional equivalent of storage coefficient or **storativity**, and is equal to storativity divided by aquifer saturated thickness. **GWAC.** See discussion under **storativity**.

specific yield: Of aquifers, see **yield (1)**.

spring: A location where ground water has communication with the atmosphere and sufficient hydraulic pressure to force the water to the surface of the ground. See also **artesian water.**

spurt loss: Pertains to the mud filtrate loss by invasion of mud filtrate into the formation as the bit passes through the formation. This quantity of the filtrate loss is controlled by the permeability of the formation until the permeability of the mud filter cake decreases to the extent that it becomes the controlling permeable medium for all further filtrate loss.

SPWLA: Society of Petrophysicists and Well Log Analysts; 1984 Glossary, second edition, compiled and edited by Robert C. Ransom.

squeeze cementing: During or after the well **completion** operation, when it has been discovered that, by faulty completion practice, the **annular space** between the casing and the formation has not been completely filled with cement and, therefore, aquifers have not been effectively isolated, squeeze cementing sometimes is an appropriate remedial action to take. By perforating the casing at the location where a cement void or **channel** occurs and using appropriate plugs, squeeze cementing of the annular space to create a barrier in the annular space is performed by forcing a cement slurry under pressure to specific locations behind the casing in a well bore. The purpose is to prevent **crossflow**, or out-of-zone communication, and prevent contamination between aquifers, or between aquifers and the well bore.

standard conditions: STP. Standard conditions of temperature and pressure of 60° Fahrenheit and 1 atmosphere pressure of 14.7 psi.

state engineer: The state engineer is charged with the administration of the waters of the State of Colorado. In times of water shortages, the state engineer or his representative determines what water rights may divert water and in what amount. **Douglas Co.**

static: At rest. Immobile.

static fluid level: A misnomer. It refers to the level that <u>liquid</u> (water in the case of aquifers) rises in a well bore when production has been stopped or the well has been **shut in**.

static mud column pressure: The hydrostatic pressure of the drilling mud against the formation at the depth of interest when drilling has been stopped.

static water level: See **water level (1)**.

stiff diagram: A rose type or polygonal diagram designed to represent specific and significant ion concentrations derived from a water analysis. The length of the radii or ribs from a central spine are scaled in the units for the concentration of each specific ion. The shape of the polygon facilitates easy recognition of the ionic profile for each water of interest. The polygonal profiles of waters provide instant recognition of changes in and comparisons of different waters at any time, time interval, and against the EPA recommended limits. See **water analysis.**

stimulation: Any means that will increase permeability and, thus, production or injection rate. See **acid treatment** and **hydraulic fracturing.** Also see **formation damage.**

storage: A finite volume with the capability to be intentionally filled and intentionally emptied. A finite volume without relief, that will maintain its pressure over time. See **injection of potable water for storage purposes.**

Storage coefficient: See **storativity.**

storage right: A right defined in terms of the volume of the water which may be diverted from the flow of the stream and stored in a reservoir or lake to be released and used at a later time either within the same year or a subsequent year. Storage water applications are submitted to the water court for adjudication and decree the same as other water rights. **Douglas Co.**

storativity: Coefficient of storage. Volume of water released per unit area of aquifer and per unit drop in head. Storage coefficient is a function of the compressive qualities of water and matrix structures of the porous material. A confined aquifer's ability to store water is measured by its storage coefficient. Storativity is a more general term encompassing both or either storage coefficient and/or **specific yield. GWAC.**

Storativity of a **confined aquifer** generally is considered to be of importance when pressure is declining. As water production continues, water pressure declines. Along with this pressure decline two things can happen. Water will expand and **compaction** of the aquifer framework can occur resulting in the expulsion of water from the aquifer. These are not related events, but both result from a decline in water pressure. Each is an independent event, but both occur simultaneously.

For the storativity calculation, the source of the water released by either or both of these two events is the water in the aquifer itself. Storativity is the amount of change in the volume of ground water related to the surface area of the aquifer for each unit change in pressure. This is not a completely reversible process. The aquifer is not likely to rebound due to the permanency of the compaction process.

As the pressure in the aquifer reduces, so does the pressure in the surrounding clay shales. Storativity does not account for the water that is expelled from clay shales during the compaction process. This water seeks relief in porous and permeable aquifers as water production continues. See discussions in **compaction (2)**, **rebound**, **bulk modulus**, and **subsidence.**

strata, stratum: A bed(s) or subdivision of the same material within a lithographic sequence or formation.

stratified: Formed, arranged, or laid down in layers. The term refers to geologic deposits. Layers in soils that result from the processes of soil formation are called horizons; those inherited from the parent material are called strata. **NSSH.** See **strata.**

stratigraphy: The branch of geology that deals with the definition and interpretation of layered earth materials, the conditions of their formation, their character, arrangement, sequence, age, and distribution; and especially their correlation by the use of fossils and other means. **NSSH.**

stream, streamflow: (1) In aquifers. A natural migratory stream within an aquifer. Both terms refer to the movement or migration of ground water in the permeable pathway from the geographical location of its source or natural recharge area to the geographical location of its withdrawal, production, or other form of relief. Also see **pass-through aquifer.**

(2) On ground surface. Refers to the commonly known tributary stream, creek, or small river.

(3) In physics. Streamflow is streamline flow or laminar flow of fluids, as opposed to turbulent flow.

(4) Discharge that occurs in a natural channel. A more general term than runoff, stramflow may be applied to discharge whether

or not it is affected by diversion or regulation. **GWAC.**

stream depletion: In water wells. The depletion of streamflow caused by the operation of producing wells completed in the same aquifer.

stuck pipe: Drill pipe, drill collars, **casing**, or **tubing** that has inadvertently become lodged immovably in the borehole. It may occur when drilling is in progress, when casing is being run in the hole, or when the drill pipe is being hoisted. **SPWLA.** The problem usually occurs where the pressure in the formation is greater than the pressure in the borehole.

sublimation: The physical process by which a solid changes to a gaseous state without passing through the liquid state. See also **evaporation.**

subsidence: (1) Is the sinking of the ground surface, overlying permeable strata, that results from the gradual dewatering and **compaction** of clay shales and other sediments overlying the strata. Depletion of water pressure in an aquifer as a consequence of excessive water production is a leading cause of subsidence. There are many examples of subsidence resulting from groundwater production due to agricultural or municipal withdrawals. Other examples where significant subsidence has taken place are: Long Beach, California resulting from oil production; and Venice, Italy resulting from industrial water production. See **compaction (2)** for explanation of the subsidence process. Also see **rebound** and **bulk modulus(3 and 4).**

There are a number of ways to measure subsidence. Most involve methods where measurements are made at the ground surface. However, probably the best, and the method that will produce the most accurate and detailed measurements, is by the satellite method known as *Interferometric Synthetic Aperture Radar*, InSAR. What is InSAR? Click on the following link to go to explanations:

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http://volcanoes.usgs.gov/insar/public_files/InSAR_Fact_Sheet/2005-3025.pdf

(2) Sinking of the ground surface resulting from underground displacement caused by a fault, or caused by the collapse of caverns or karsts created by the dissolution of **sedimentary** minerals.

(3) Sinking of the ground surface resulting from surface disturbance.

suction: A generic term. Suction refers to a condition, function, or location, such as suction pump, suction line, suction cup, suction process. Suction is the artificial reduction of pressure in one of two contacting mediums, so that the higher pressure of the other medium can provide force to perform a function. That is, in a system where two communicating, but separate, pressures are balanced, suction unbalances the pressures so that the higher of the two pressures provides the force to control the function, whether it be drawing on a straw in a soda can or pumping to empty a septic tank. Suction can create neither energy nor force, and can perform no work. A vacuum is a condition resulting from perfect suction. A vacuum is the absence of matter, energy, and force; and, therefore, can perform no work. Suction creates a condition where a pressure differential provides the energy and the force to do work. The pressure differential is similar to a steep pressure gradient. See **pressure gradient**.

The maximum height in feet that water can be lifted by a *suction-produced* pressure gradient is: the quantity (prevailing **atmospheric pressure** in psi) divided by the quantity (0.433 times the **specific gravity** of the water being lifted).

supplant: Relative to water supply, to replace or to add reused or reclaimed water to the water supply system. A conservation measure to prevent waste.

surface casing: In water wells. It is a length of casing long enough to protect the hole from collapsing and to isolate near-surface aquifers. Surface casing in all water wells must extend at least 19 feet into the ground from the **wellhead** and end at least 1 foot above the ground to prevent contaminants from entering the well. See also **protection casing**. Where the surface casing in water wells is steel, a longer length of casing made of PVC or steel, run to the bottom of the borehole, often is used for the final **completion** of the well. Here, the longer length of surface casing also serves as the **production casing**.

In oil and gas wells, the overall length of the surface casing can be several hundreds of feet or several thousands of feet depending on the total thickness of the aquifers to be drilled and protected. The surface casing must be completed properly in order to isolate the aquifers from each other and protect them from contamination during the drilling process, and keep them free of contaminants throughout the completion and production processes. See **completion.**

surface pressure: The pressure in the well bore measured at the **wellhead.**

surface tension: Of liquids. It is the intermolecular cohesive force provided by the attraction of like molecules, most often observed at the surfaces of liquids, or at the interfacial contact between immiscible liquids (emulsions). The intermolecular attraction and cohesive forces act *within* the body of liquids, and the amount of matter gravitates to its smallest volume, resulting in the smallest surface area that can surround that volume. Examples: A rain drop; or two droplets of water that readily merge to form a single droplet containing the two volumes, but exhibiting a smaller total surface area.

Surface tension is a naturally occurring phenomenon that takes place at the interface or intersurface contact between two immiscible liquids, or a liquid and a gas. The intermolecular attraction is not a variable force dependent on its environment or surroundings, it is a property of the molecule. It is a near constant force that can be redirected by like adjacent molecules somewhat similarly as a magnetic field can be reshaped. The intermolecular attraction *within* a liquid is directed equally in all directions. The molecular attractions of the surface molecules have been distorted directionally toward side-to-side molecules as well as interior molecules, thus reinforcing and increasing their mutual side-to-side cohesive attractions or tensile properties.

surface water: Water on the earth's surface, such as rivers, streams, ponds, lakes, oceans, etc.

surge irrigation: A method o irrigation using computerized valves to turn the water supply on and off to move water more uniformly down the field. **CSU.**

TD: Total depth of the drilled hole.

TDS: See total dissolved solids.

tertiary recovery: See under **recovery.**

tectonic: Pertaining to the deformation of the earth's crust and rock formations, resulting from external forces and events.

thermogenic methane: Thermogenic methane is created by the thermal decomposition of buried organic material. It is found in rocks buried at deeper depths within the earth and is produced from oil and gas wells. The COGCC has consistently found that biogenic gas contains only methane and a very small amount of ethane, while thermogenic gas contains not just methane and ethane but also heavier hydrocarbons such as propane, butane, pentane, and hexanes. **COGCC**. See **methane**, **biogenic methane** and **flaming water**.

thief level: When crossflow occurs, it is the level in a producing water well where water from an unauthorized aquifer merges with and is withdrawn along with waters from an authorized aquifer. See **crossflow (2)**.

thief zone: When crossflow occurs, it is a zone at lower water pressure
taking or accepting the waters cross flowing from one or more other aquifers at higher pressure. See **crossflow (1)**.

tortuosity: Related to the crookedness and meandering of a porous and permeable pathway. A measure determined by the ratio of the actual length of the porous and permeable pathway between two points to the straight line length.

total consumptive use: The amount of water, regardless of its source, used by crops during the growing season. It is the amount of water that is physically removed from the stream's system and is not available for other users on the stream. **Douglas Co.**

total depth: TD. The total depth of the drilled hole.

total dissolved solids: TDS. The total dissolved mineral matter in water. A general indicator to the quality of the water. Often referred to in units of parts per million, ppm (wt./wt.), but usually measured in units of mg/liter (wt./vol.). Water with TDS of more than 500 mg/liter is considered to be of marginal health quality and might contain excessive amounts of undesirable ions such as calcium, magnesium, nitrate or sulfate. That in sea water is about 35,000 ppm.

transfer: The process of moving a water right originally decreed to one ditch to another ditch by court decree. A transferred water right generally retains its priority in the stream system and may or may not retain its right to divert its entire decreed amount. **Douglas Co.**

transmissivity: The expression of the potential flow capability of an aquifer. Transmissivity is a property that allows direct comparison of the unique flow rate potential for each aquifer. Transmissivity is the product of **hydraulic conductivity** and net saturated thickness. In the detailed analysis of **Darcy's equation** found under **hydraulic conductivity** the hydraulic conductivity is shown to be a part of Darcy's equation. The net saturated thickness is obtainable from **petrophysical well logs.** See the equation form for transmissivity developed in the discussion under **hydraulic conductivity.** Also see **flux.**

transpiration: The process by which water in plants is transferred as water vapor to the atmosphere. **Douglas Co.**

trap: Refers to a natural reservoir where the boundaries of porosity are determined by structure, permeability, or stratigraphy. Can capture migratory oil and/or gas due to the difference in density of crude oil and/or gas from that of formation water.

treat: To filter, aerate, and/or add chemicals to improve the quality of ground water or reclaimed water. Most often to remove undesirable ions, bacteria, and other pollutants, generally to improve the quality of used or reused water.

treated: Describes water that has been subjected to filtration, aeration and/or chemical means to improve its quality.

tributary: A tributary is generally regarded as a surface water drainage system that ultimately connects with a river system.

tributary ground water: All water from the earth's surface, such as from meteoric precipitation, rivers, lakes, and streams, that has penetrated the soil by infiltration and percolation, and has become part of the natural stream of an aquifer. Tributary ground water exhibits communication with the atmosphere and atmospheric pressure and sometimes exposure at the ground surface; and, therefore, is a water supply **renewable** by natural means. See **unconfined aquifer** in **aquifer (1).**

tubing: The small diameter pipe, connected to a pump, inside the casing of a well through which water or other fluids can be pumped or forced to the surface.

unappropriated water: Water that has not been appropriated, and which no person or entity has claims or superior rights.

unconfined aquifer: See **aquifer (1).**

unconformity: A discontinuity interface in the depositional pattern of sediments. The *erosional interface* between older and younger sediments.

unconsolidated: In granular sediments, it pertains to the lack of rigidity because binding by water-borne cementing minerals has not taken place. Compare **consolidated.**

underflow: (1) Ground water flow within a streambed below a surface stream; (2) lateral movement of water through the soil zone, also known as interflow. **GWAC.**

unnatural: Manmade, manufactured, reclaimed, reused, a substitute for the natural.

unnatural recharge: The downstream act to add to or replenish a resource that is being exhausted. A downstream man-made means by which reclaimed water is returned to an aquifer. A conservation measure not part of the **hydrologic cycle** and not to be confused with **renewal.**

unsaturated zone: This is the **aerated zone.** Sometimes called *vadose* zone.

use: (1) To consume, to exhaust, to exploit.

(2) For consumption.

user supplied data: Data or records of water uses provided by an owner/user that has not been verified by state officials. **CSU.**

vacuum: See **suction.**

vadose zone: See **aerated zone.**

vapor intrusion: See **soil vapor intrusion.**

vapor pressure: See under **evaporation.**

viscosity: Degree of being viscous. A measurement related to the internal properties of a liquid that offer resistance to flow. Demonstrated by the thickness or thinness of a liquid. Internal friction caused by molecular cohesion in liquids. Viscosity may be reported in different ways:

(1)Marsh funnel seconds. The time it takes for 1000 cm^3 of **drilling mud** or other liquid to flow through the funnel. The longer the time in seconds, the more viscous is the mud.

(2)Yield point and plastic viscosity in centipoises. Using the combination of plastic viscosity and yield point, the plastic viscosity indicates the flow characteristics of the fluid when it is moving rapidly, and the yield point indicates the flow characteristics when it is moving very slowly or at rest. In both cases, higher values indicate a more viscous fluid. **SPWLA.**

volume: Of water. A specific quantity of water generally expressed in terms of acre feet. An acre foot is defined as the amount of water required to cover one acre of land to a depth of one foot and is equivalent to 43,560 cubic feet or 325,872 gallons. **Douglas Co.**

vug, vugular porosity: Secondary porosity formed in sediment by the dissolution of soluble minerals and/or enlargement of micro-fractures.

wastewater: Water that has been used. Effluent. Might contain unhealthy waste or unwanted substances, pollutants, or other contaminants.

wastewater treatment: See **treat** and **treated.**

water analysis: A chemical analysis of a water solution in which specific ions and their concentrations are determined and recorded. The character of the water solution then can be described in terms of the individual ion concentrations and the total dissolved solids, in units of ppm or mg/liter. A complete analysis will include measurement of **pH, hardness**, and bacteriological testing. For limits of these criteria recommended for good quality domestic water, suggested by U.S. Environmental Protection Agency (EPA), consult EPA 822-R-94-001, May 1994 or **CSU**. See also **biochemical oxygen demand** and **stiff diagram.**

water and sanitation districts: A special taxing district formed by the residents of the district for the combined purpose of providing potable water and sanitary wastewater services. **CSU.**

water balance: A mathematical construction that shows the amount of water leaving and entering a given watershed or aquifer. **GWAC.**

water block: For aquifers only. It pertains to the blockage in the pores of an aquifer, related to the disturbance of the equilibrium existing in the pores, by the introduction of mud filtrate or other water injected into the aquifer. This kind of blocking can be related to swelling of clays or other disturbance to clay particles and crystals. This is not the complete usage of the expression as it is used in oil or gas wells.

water commissioner: State water officials, appointed by the state engineer and working under the direction of the division engineers, who perform the day-to-day administration of surface and ground water in each water district. **CSU.**

water conservation: See **conservation** and **xeriscape.**

water court: A special division of a District Court with a District Judge designated as and called the Water Judge to deal with certain specific water matters principally having to do with adjudication and change of point of diversion. There are seven water courts in Colorado. **CSU.**

water cycle: See **hydrologic cycle.**

water drive: See under **recovery** and **drainage.**

water districts: Eighty geographical divisions of the state that originally were used for the granting of water rights. The districts are now largely used for administrative purposes. **CSU.**

water divisions: The seven geographical areas of the State of Colorado corresponding to the major natural surface water drainages. **CSU.**

water flux: A volume of water per unit area per time. **GWAC.**

water level, water level depth: (1) In an inactive water well, the depth from the ground surface to the surface of the static column of water inside the cased or uncased well bore when the pressure of the water column or **hydrostatic head** counterbalances the formation-water pressure or pore pressure at the drilled face of the aquifer.

(2) In an active water well, the depth from the ground surface to the surface of the column of water inside the cased well bore under dynamic or producing conditions. During production the well pump will reduce the height of the water column in the well, increasing **drawdown**, and thus decreasing **back pressure** opposing the flow of water into the well bore. See **drawdown.**

water loss: (1)Pertains to the quality of drilling mud. It is a measure of mud filtrate passing through mud cake over a specific length of time.

(2) Generic. Can be **evaporation** or **percolation.**

water pressure: Relative to aquifers. Pore pressure. Formation pressure. Usually hydraulic, sometimes hydrostatic.

water quality standards: A plan for water-quality management consisting of four major elements:

(1) The uses to be made of water (recreation, household, fish and wildlife propagation, industrial and agricultural) .

(2) Criteria to protect the water to keep it suitable for use.

(3) Implementation plans (for necessary industrial- municipal waste treatment improvements).

(4) Enforcement plans and anti-degradation statement to protect and maintain desired high quality standards.

water right: A right to use, in accordance with its priority, a certain amount of the waters of the State by reason of the appropriation of the same CRS 37-92-103). **Douglas Co.**

watershed: The region draining into a river, river system or body of water; the total land area, regardless of size, above a given point on a waterway that contributes runoff water to the flow at that point; all the land that serves as a drainage for a specific stream or river. **CSU.**

water storage: The places where water can be stored and recovered.

They can be on the ground surface or above ground in lakes, ponds, impoundments, reservoirs, tanks; or below ground in aquifers. See **injection of potable water for storage purposes.**

water table: The shallowest air-water interface of water-saturated earth, gravel, sand, or porous rock where the pressure at the interface is at atmospheric pressure. Might have seasonal variations. Also see **perched water table.**

water transfer: The legal change in a water right reflecting some combination of a conveyance of ownership of diversion, place of use, and/or type of use to another. **GWAC.**

water well: For the purpose of producing water. A well is normally drilled or dug into a water-bearing earthen material and then equipped with a means for power, a casing, tubing, pump and motor to produce the water. A water well consists of the entirety of all facilities, fixtures, fittings and instruments, above ground and below ground, necessary to produce ground water.

weathered, **weathering:** Exposure, over a period of thousands if not millions of years, to wind, rain, freezing, leaching, sun, erosion and all other natural attacks often results in degradation of the original material. The characteristics and properties of an **outcrop**, or near surface rock, might have characteristics and properties quite different from the buried and protected rock. All weathering of the exposed rock or outcrop increases those factors that increase the **permeability** of surface samples.

weir: A vertical structure in an open channel with a calibrated opening that measures water's rate of flow. See **flume. GWAC.**

well: Pertaining to water, see **water well.**

wellhead: The fixture or equipment at the surface of a well, connected to the casing, that allows access to the well bore and downhole equipment.

Wellhead Protection Program: An amendment to the federal Safe Drinking Water Act in 1986. Initiated to minimize the potential for contamination of public ground water supplies. **CSU.**

well log: A generic term for the geophysical or petrophysical records that are recorded at the surface from measurements made by scientific instruments run in the borehole. A permanent record made from the measurements taken by downhole instruments as the instruments are drawn through and past the well bore environment by a winch-drawn electrical cable. Well logs are used to identify and correlate underground formations, beds, and strata; identify the mineralogy of the rocks and fluids they contain; and to determine their physical properties and characteristics.

The first electrical, downhole, well log was run by Henri G. Doll on
Sept. 5, 1927 in the Pechelbronne oil field in France for Societe de Prospection Electrique, a company newly formed by brothers Conrad and Marcel Schlumberger. Electrical measurements were taken by hand at 1 meter intervals in the 500 meter drilled hole. The method first was called Electrical Coring, later to be called Electrical Survey.

(1) Any of a number of different measurements taken by downhole instruments in the *open, uncased borehole* for the purpose of making records of different conditions, characteristics and properties of earthen formations, beds, and strata and the fluids they contain.

(2) Any of a number of different measurements made by downhole instruments in the *cased borehole* environment through plastic or steel casing, primarily for the purpose of determining the quality of the **completion** of the well and/or evaluating the performance of the well.

(3) Logs made by collecting information at the surface; for example, analysis of cuttings brought to the surface by drilling mud.

well logging: A generic term related to the specific discipline pertaining to the recording of geophysical or petrophysical well logs and the analysis and interpretation thereof.

well permit: The granting of permission by the State Engineer allowing the digging of a hole in search of ground water to apply to a beneficial use. A written permit obtained by the state stating permission to dig a hole to find ground water. **GWAC.**

well screen: This term is used in water-well language to refer to the slots or perforations that are placed in the casing at the depth intervals of the aquifer or aquifers to be produced.

well-to-well interference: See **equity determination**, also see **deplete** and **depleted (2)**.

well yield: The pumping rate that can be supplied by a well without drawing the water level in the well below the pump intake. See **yield. GWAC.**

wetland: A lowland area that can be or is regularly wet or flooded, such as a marsh or swamp, or lowland drainage area.

wettability: The ability of a solid to be wetted by a contacting liquid. A function of the molecular adhesive forces between a liquid and solid and the intermolecular cohesive forces that tend to draw the like molecules of the liquid together. The degree of wettability of a solid by a specific liquid is determined from a droplet of the liquid on the solid by measuring the contact angle formed between a tangent on the droplet at the liquid-solid contact and the plane of the solid surface. The greater the angle, as if the liquid were spreading over the solid surface, the greater is the wettability of that solid for that liquid. Wettability relative to a specific liquid can be increased by the introduction of a reactive agent that reduces the **surface tension** of the specific liquid.

whipstock: A long, steel, cased wedge-like device used during the drilling process to deflect the drill bit in a predetermined direction. Used in directional drilling and slant holes.

withdrawal level: The withdrawal level is usually thought of as the level from which water is produced. Must be specific: (1) Commonly thought to be the vertical depth where water emerges from the face of an aquifer.

(2) Inside the casing, the depth where water moves from outside the casing to the inside. In this case, depth of slots or perforations.

(3) Inside the casing, the depth of the ports of the water pump.

withdrawal, withdrawal process: It is commonly thought that water is *drawn* or *withdrawn* from an **aquifer** by the well pump. This is not wrong, but it is not technically accurate. Technically, the water from an aquifer is not *withdrawn* from the formation, it is withdrawn from the inside of the **casing** in the well bore. (Side note. The water-well pump cannot draw water to the well bore by *suction*. A vacuum, even if it could be created, cannot drive water to the well bore because a vacuum is neither a source of energy nor a form of force. See **suction.**) Water in the aquifer is *driven* into the well bore and the casing by **hydraulic pressure**, wherein the water then can be *lifted* to the ground surface by a pump where it is further withdrawn from the well. For every **formation** and every **formation pressure**, there is a specific hydraulic **pressure gradient** that is required for water to be driven toward and into the well bore. This gradient is influenced by both the **hydrostatic head** inside the water-well casing (through **drawdown**), and the formation pressure. Without a driving mechanism, and without the driving force of sufficient hydraulic pressure, there cannot be sufficient pressure gradient toward the well bore, and water cannot be produced, but simply will remain **in place.** For a better understanding, see **aquifer**, **drainage**, **drive mechanism**, **hydrostatic load**, **hydraulic pressure**, **pressure gradient**, **pumping process.**

work over: Related to remedial operations on or in a well to correct mechanical problems, perform **squeeze cementing** operations, set plugs, perform acid treatments, etc.

xeriscape: The conservation of water through creative landscaping and the use of plants and shrubs that are drought tolerant and can subsist on natural precipitation, or require only small amounts of supplementary water. The term **xeriscape** was copyrighted by Denver Water in 1981.

yield: (1) **Specific yield** of aquifers, an estimation. The volume of water that can be drained by **gravity** from the pores of sand, gravel, soil, or rock divided by the total volume of material and expressed as a fraction or percent. **GWAC.**

This method applies to **gravity drainage** and describes yield without regard to the porosity of an aquifer. This is the method recommended in Senate Bill 5 by the Colorado legislature. See **Senate Bill 5**, **capillarity**, **buoyancy**, **drainage** and **recovery factor.** Compare **irreducible water.** See also **equity** and **equity determination.**

(2)The volume of water diverted by a water right. Yield may be expressed as an average for a period of years (average yield) or as the yield of one selected year representing the lowest or critical amount of water provided (critical year yield). Yield also may refer to diversion at the headgate (headgate yield) or at the farm turnout where it is applied to irrigation (farm yield). The difference between headgate yield and farm yield is the amount of water lost to seepage and other causes related to the conveyance of water through the ditch.

(3) See also **safe yield**.

ABOUT THE EDITOR

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