AN INTRODUCTION TO HYDROLOGY

Prepared for

WATER RIGHTS MEDIATION TRAINING

by
THE IDAHO MEDIATION ASSOCIATION
and
THE IDAHO DEPARTMENT OF WATER RESOURCES

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1. Introduction

This booklet offers an introduction to Idaho hydrology as part of water rights mediation training for the Idaho Mediation Association. The booklet includes an overview of surface and ground water hydrology, a glossary of hydrologic terms, and a list of commonly used units and conversions. Because the mediation training focuses on the Snake River water rights adjudication, the booklet also focuses on the hydrology of the Snake River Plain.

2. The Water Cycle

Water cycles continuously through the atmosphere, on the earth's surface in rivers, lakes and oceans, and below the earth's surface in the form of ground water. This constant movement is known as the *hydrologic cycle* (Figure 2-1). Water evaporates from oceans, condenses in the atmosphere, and falls to earth in the form of rain, snow, or hail. Water completes the cycle when it returns to the ocean via the land surface or by direct precipitation.

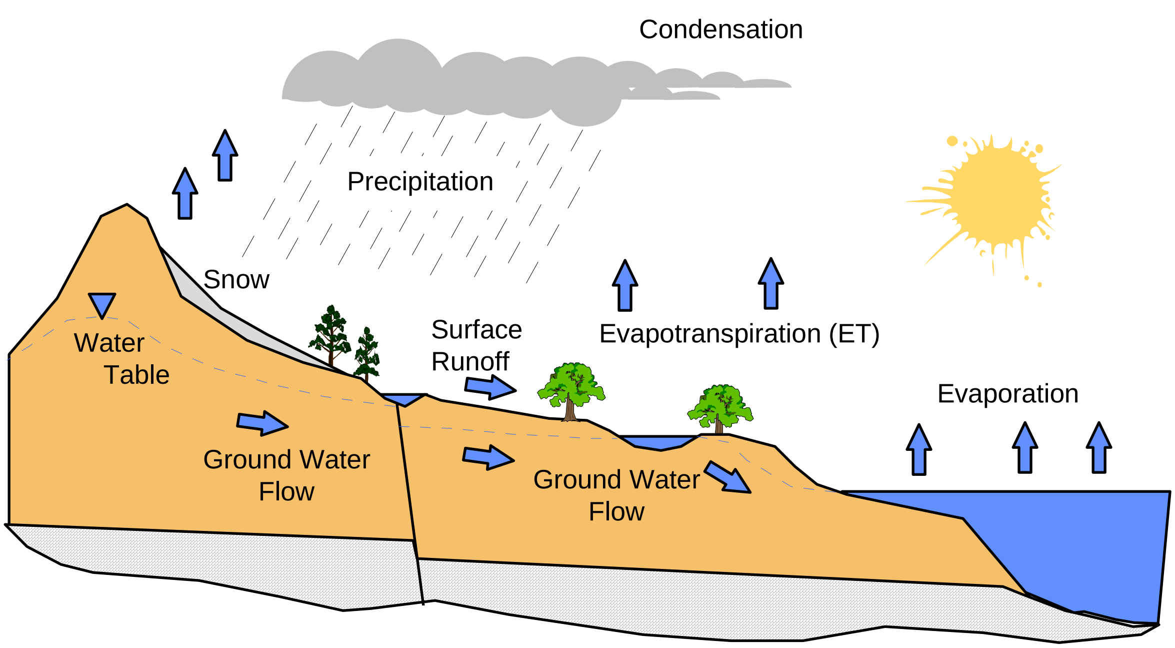

Figure 2-1. The hydrologic cycle.

Water that falls onto the earth's surface may follow several different pathways. Some of the water flows across the land and in stream channels, as *overland flow* or *channel flow*.

These surface waters may evaporate directly, seep into the subsurface, or flow into lakes or oceans.

Some of the rainwater seeps into porous soils by *infiltration.* Plants consume large quantities of this soil moisture. Plants release water into the atmosphere by *transpiration.* A small fraction of soil moisture *evaporates* directly into the atmosphere. The process of transpiration by plants and evaporation from ground is known as *evapotranspiration.*

Excess soil moisture moves downward through soil and rock by gravity. Water first passes through the *unsaturated zone,* where both water and air occupy the pore spaces between rock and soil particles. Eventually this water reaches the *saturated zone*, where all pore spaces are filled with water. Ground water flows through the rock and soil layers of the earth until it *discharges* as a spring or seeps into lakes, streams, or the oceans.

3. Surface Water

Rivers and streams are the lifeblood of Idaho. This is especially true for southern Idaho, where a single river system – the Snake River and its tributaries – nourishes and drains all of central and southern Idaho. Without water from the Snake River southern Idaho would be a desert, unable to support its highly productive agricultural system.

The eastern Snake River Plain contains some of the most productive farmland in Idaho. The plain is about 170 miles long, 60 miles wide, and covers approximately 10,800 mi^2. Elevations range from about 2,500 feet in the west to over 6,000 feet in the easternmost areas. The Snake River enters the plain at an elevation from 5,019 feet near Heise to leaves at an elevation of 2,495 feet near King Hill.

Precipitation on the plain ranges from approximately 8 to 10 inches annually; precipitation in some of the mountain areas surrounding the plain exceeds 60 inches. Most of the precipitation occurs during the winter months in the form of snow; precipitation in the lowlands is spread more evenly throughout the year (Garabedian, 1992).

Natural vegetation in the plain is sparse because of the arid climate. Major crops include potatoes, small grains, sugar beets, beans, alfalfa seed, and hay. Most of these crops are grown with irrigated water.

Over 9 million acre-feet are diverted annually from the Snake River system for irrigation (Garabedian, 1992). Approximately 5 million acre-feet of water can be held in reservoir storage for irrigation (Kjelstrom, 1980). Surface water used for irrigation is currently the largest source of ground water recharge.

The last century has seen the evolution of a complex water distribution system for agricultural irrigation in the Snake River Plain. In general, a surface water distribution system may consist of a variety of structures. These can be categorized as (1) conveyance structures, (2) regulating structures to control flow, (3) water measurement structures, and (4) protective structures (Aisenbrey, Jr., et al., 1974)

Conveyance structures consist of canals (Figure 3-1), and may include inverted siphons to carry canal water under natural channels or other features, road crossings to carry water under roadways, bench flumes to convey water along steep hillsides, or drop or chute structures to lower water down a hillside. Canals may be unlined or lined. Concrete is a common lining material; canals are lined to reduce channel scour and seepage.

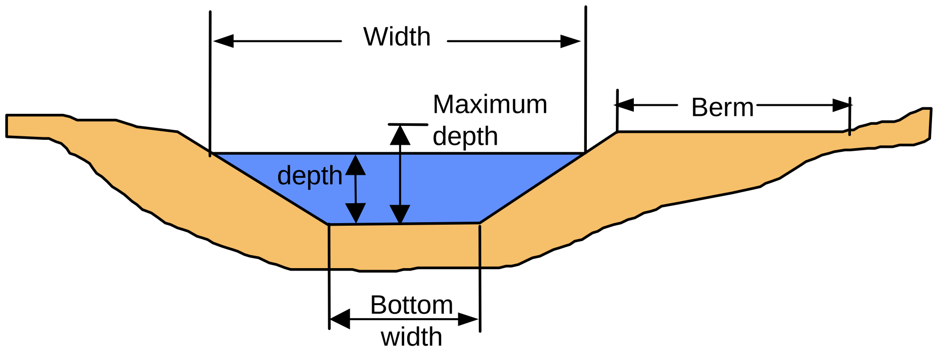

Figure 3-1: A typical canal in cross section.

Regulating structures may include a diversion dam on a stream or river, a turnout from a larger canal, or a pumping plant located on a large canal or reservoir. A headgate is shown in Figure 3-2. A check structure also may be used to regulate water levels in a canal when the canal is flowing at less than its design capacity, so that a turnout structure may still be used to deliver a design capacity.

Water measurement structures are required for gauging rates of flow and delivery volumes. Water measurement devices may include flumes, weirs (Figures 3-3 and 3-4), open flow meters, and constant head orifices. A flume or a weir allow a known flow rate to pass at a given depth.

Finally, protective structures are designed to protect the canal or other conveyance structures on an uphill side from damage by storm water runoff, or internally from excess storm flows or misoperation (e.g., wasteways).

Flow in a canal is generally described as a volume of water per unit of time. Water flow rates typically are given in the units of cubic feet of water per second (cfs). For example, A canal carrying 100 cfs has 100 cubic feet of water flowing through a particular cross section every second.

Figure 3.2: Headgate structure for regulating flow.

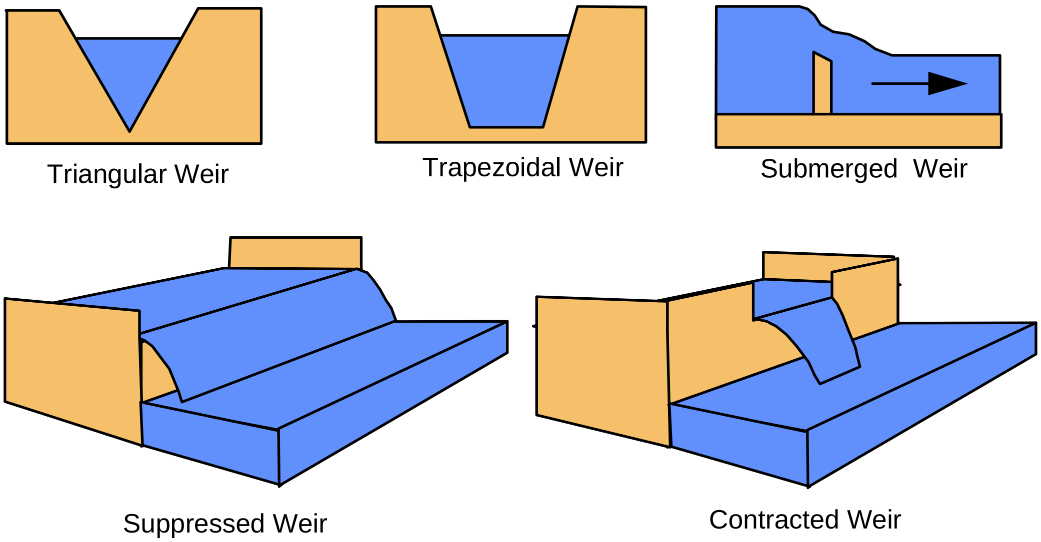

Figure 3-3: Types of weirs.

Figure 3-4: Contracted weir.

The rate of flow can be described with the following equation:

$$Q = vA \quad \text{where}$$

Q = flow
v = velocity
A = cross sectional area.

The flow velocity in a channel depends on the (1) hydraulic radius of a channel (the ratio of the cross sectional area containing water to the wetted channel perimeter), (2) channel roughness, and (3) channel slope. In general, the greatest flow velocities in a channel are near the center of a channel, and below the water's surface.

Water application rates to fields sometimes are described in acre-feet per year; reservoir storage volume are usually counted in acre-feet. An acre-foot of water is the amount of water needed to cover one acre (43,560 ft^2) with one foot of water. One acre-foot holds 325,851 gallons.

A miner's inch is an older measure of flow, the definition of which varies from state to state. In Idaho, 50 miner's inches equal one cfs, or about 9 gallons per minute. This is a typical flow from a garden hose.

4. Ground Water

4.1. The Basics

Ground water is any water that exists beneath the earth's surface in interconnected pores in rock or sediment. The term ground water includes water in both saturated and unsaturated zones.

The unsaturated zone may be divided into three subzones: the *soil zone,* the *intermediate zone* and the *capillary fringe* (Figure 4-1). The soil zone supports plant life. The intermediate zone extends from the soil zone to the capillary fringe. The *capillary fringe* is at the base of the unsaturated zone. Here, water clings as a film on the surfaces of rock particles and rises by capillary action through small-diameter pores against the pull of gravity, similar to spilled lemonade rising into a paper towel.

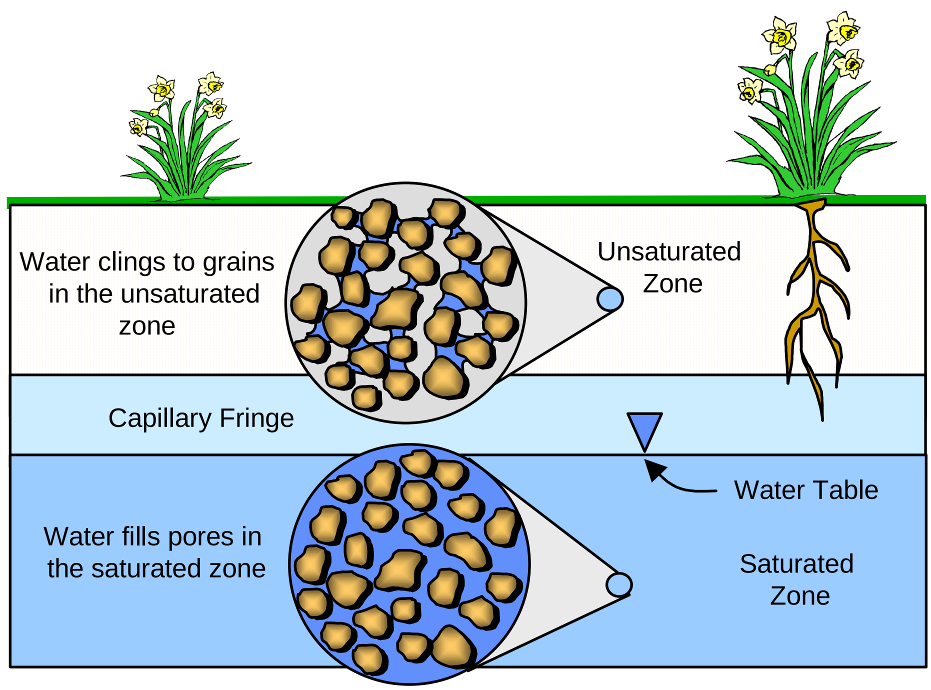

Figure 4-1. Ground water in saturated and unsaturated zones.

The boundary between the saturated and unsaturated zones is called the *water table.* The shape of the water table often resembles the shape of land surface. Hydraulic pressure at the water table is equal to atmospheric pressure. Below the water table, in the saturated zone, hydraulic pressure increases with depth, because of the weight of the water.

An *aquifer* is a water-saturated rock unit or sedimentary unit capable of transmitting significant quantities of water to wells. Water only rarely occurs in underground rivers or streams, in special geological formations. Rather, aquifers resemble rocks and soils we see at the surface, except the pore spaces are filled with water.

The ability of an aquifer to store and transmit water is a function of its *porosity and permeability*. Porosity is a measure of the void space in rocks or sediments (Figure 4-2). *Effective porosity* is the collective measure of interconnected pores. High porosity values mean that more space is available for ground water. Porosity values for common rock types are given in Table 4-1.

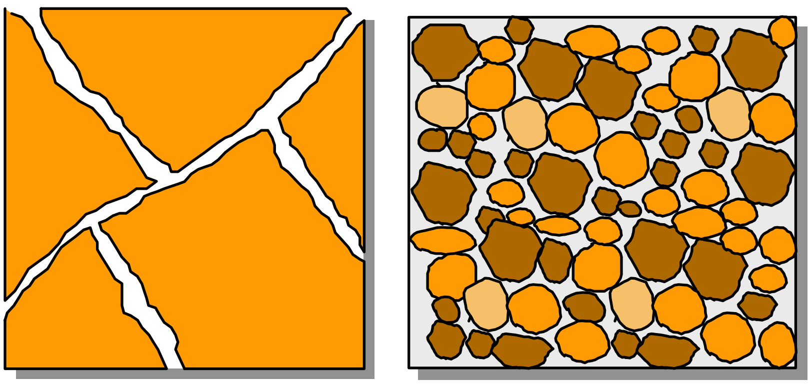

Figure 4-2. Porosity (void space) in rock fractures and unconsolidated sediments.

Material	**Porosity (Percent)**
Gravel	25 - 40
Sand	25 - 50
Silt	35 - 50
Clay	40 - 70
Fractured basalt	5 - 50
Sandstone	5 - 30
Shale	0 - 10
Crystalline rock Fractured Dense	 1 - 10 0 - 5

Table 4-1. Typical porosity values.

Porosity of sediments is determined by the shape, orientation, and sorting of sedimentary particles. Well-sorted sediment is more porous than poorly-sorted sediment because in poorly-sorted sediment smaller particles fill the void spaces between larger ones. Irregularly shaped grains tend to have greater porosity than spherical sediment grains. The orientation or *packing* of irregularly shaped grains also affects porosity of sediments.

The porosity of rocks is generally lower than that of unconsolidated sediments, although fractured rocks may be very porous. All hard rocks contain fractures caused by stress or erosion after the rocks were formed. Joints are the most common type of fracture, where blocks of rock have separated in a direction perpendicular to the fracture plane (Figure 4-3). Faults are fractures along which the rocks have moved parallel to the fracture plane. Faults and joints may provide a convenient pathway for ground water flow, or they may retard water flow. *Fault gouge* (ground up rock deposited along the fault plane) may impede ground water movement.

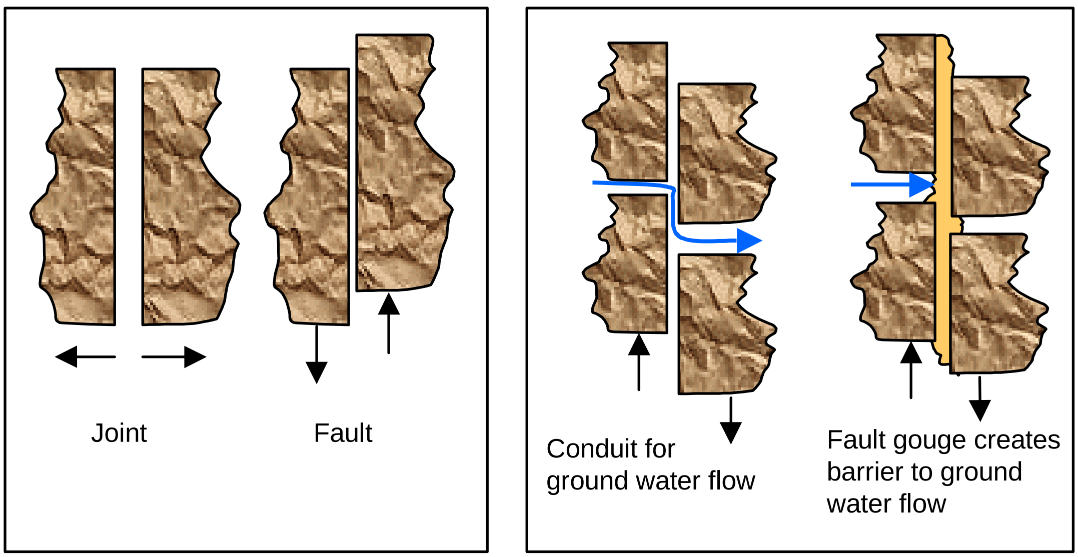

Figure 4-3. Joints and faults and their effect on ground water flow.

Permeability refers to the ability of rock or sediment to transmit water. Sedimentary layers such as clay typically have high porosities but very low permeabilities. Water occupies the tiny pore spaces between clay particles, but is held in place by molecular attraction and moves very slowly through the clay. Well-sorted, coarse sands have both high porosity and high permeability.

Aquifers may be *confined* or *unconfined* (Figure 4-4). The upper surface of an unconfined aquifer is the water table, which can rise and fall as the volume of water in the aquifer changes (Figure 3.5). The water table usually fluctuates seasonally as recharge varies. In Idaho, water levels are usually highest in the spring and early summer and lowest in the early fall, except in irrigated agricultural areas. In irrigated agricultural areas ground water levels may be highest at the end of the irrigation season.

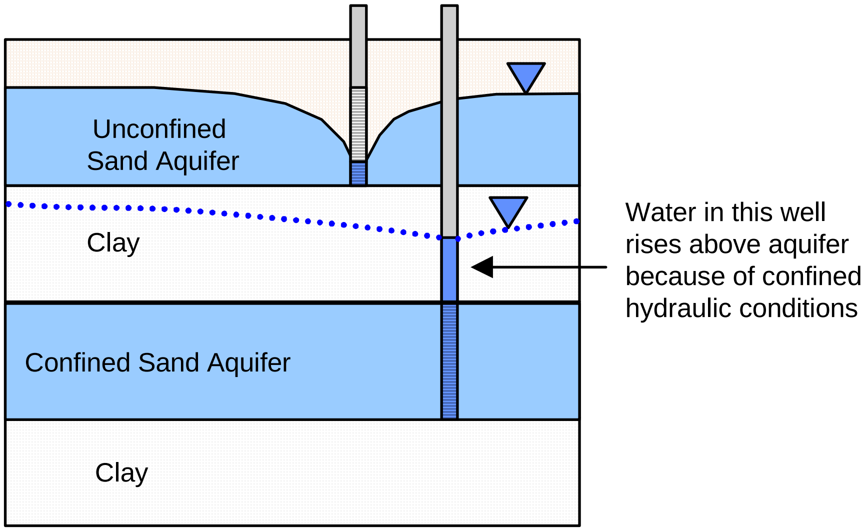

Figure 4-4. Confined and unconfined aquifers.

Confined (or artesian) *aquifers are* bounded above by a confining layer. The weight of the confining layer and the column of water create pressures greater than atmospheric pressure in confined aquifers. Because of pressure, water in a cased well will rise above the upper surface of the aquifer, to a level known as the potentiometric surface. If the potentiometric surface is above land surface, water will flow out of an artesian spring or well.

4.2. Aquifer Parameters and Ground Water Flow

The driving force for ground water movement is the *hydraulic gradient.* The principle of a potential gradient is common throughout the physical world: heat flows through solids from higher to lower temperatures, electricity moves from larger to smaller voltages, and salt in solution migrates to regions of lower salinity. Ground water moves in the direction of decreasing *total head* (Figure 4-5).

Fluid potential, or hydraulic head, can be expressed as an elevation. Total head, the elevation of water in an observation well, consists of *elevation head* and *pressure head* (Figure 4-6). The water table in an unconfined aquifer represents an elevation head. The water levels in a well penetrating an unconfined aquifer may rise above the top of the aquifer due to a combination of elevation head and pressure head. The hydraulic gradient is calculated as the difference in head between two locations divided by the distance between the two points.

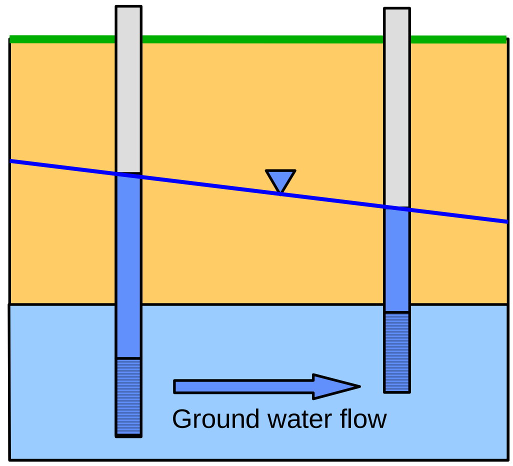

Figure 4-5. Ground water flows in the direction of decreasing hydraulic head.

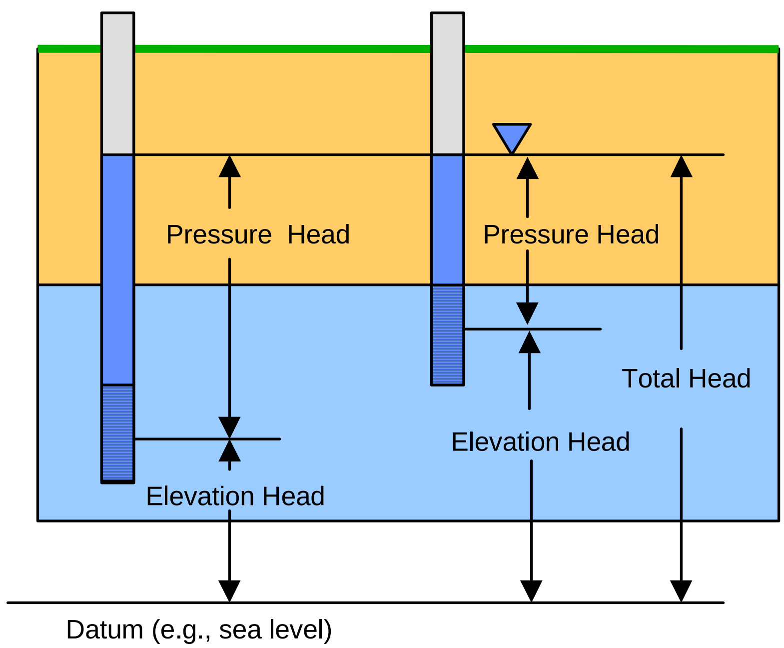

Figure 4-6. Hydraulic head consists of pressure head plus elevation head.

The force driving the water (i.e., hydraulic gradient) must overcome the frictional forces between the moving fluid and the sediment grains for water to flow. Darcy's Law describes the factors that control the flow of ground water:

$$Q = -K\,I\,A.$$

In Darcy's equation, *Q* represents the discharge – the amount of water flowing through the aquifer. *I* represents the hydraulic gradient and A is the cross sectional area of the aquifer.

K, the *hydraulic conductivity,* is a measure of the ease with which water will flow through a saturated rock or soil aquifer. The hydraulic conductivity of different geologic materials varies widely. Hydraulic conductivities are highest for materials with high effective porosity, such as sand and gravel, and lowest for silts and clays.

Transmissivity, another commonly used aquifer parameter, is the rate at which water is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. In other words, transmissivity is the hydraulic conductivity of the aquifer multiplied by the vertical thickness of the aquifer.

Storativity is also an important aquifer parameter. Storativity is the volume of water that an aquifer will release from storage per unit surface area per unit change in head. The storativity of an unconfined aquifer is its *specific yield*, the ratio of the amount of water the aquifer will yield by gravity or by pumping to the total volume of aquifer materials. The specific yield of clay and silt is generally only 2-15% of the total rock volume, whereas that of gravel and coarse sand is often 25-35% of the total rock volume. Storativity values in a confined aquifer are associated with decreases in pressure, and generally are much lower than specific yield in an unconfined aquifer.

4.3. Ground Water Flow

A ground water flow system consists of aquifer recharge, discharge, and the flow in between. Water moves in the direction of decreasing slope of the water table or the potentiometric surface. Water enters the flow system (Figure 4-7) in areas of recharge (highlands) and moves through the aquifer to areas of ground water discharge (valleys or lowlands).

Ground water flows downward from the water table in recharge areas. Ridges in the water table form ground water divides, which often coincide with surface water divides. Ground water flows in opposite directions from the divide. In discharge areas ground water flows upward, toward the water table. The water table is usually at or near the ground surface in discharge areas. Here, ground water may escape as a spring, seep, or surface stream, or may evaporate.

The movement rate of ground water depends on the hydraulic gradient and the aquifer characteristics. Shallow ground water may move at rates of less than a foot per day to several feet per day, depending on permeability and hydraulic gradient. Deep ground water sometimes moves slowly – sometimes as little as a few feet per century. Ground water flowing in open fractures, or basalt lava tubes, can move at faster rates.

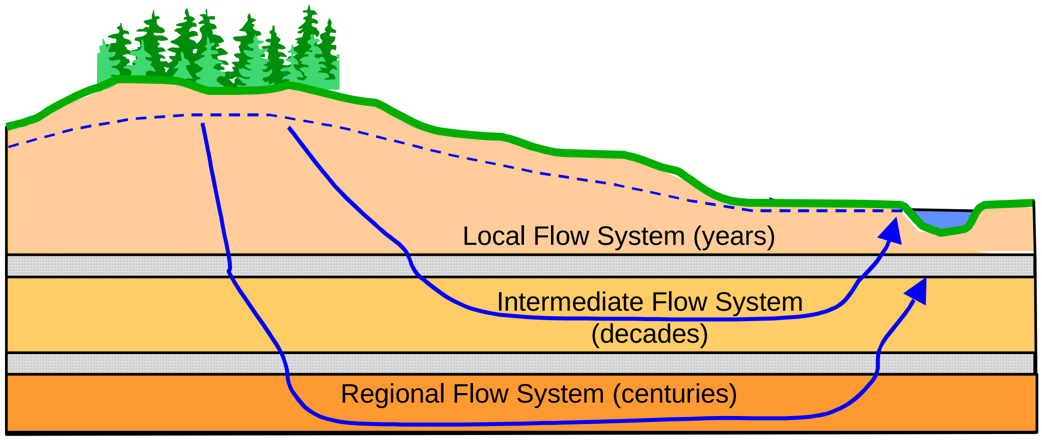

Figure 4-7. Local and regional ground water flow.

4.4. Water Wells

The primary function of a water well is to provide a conduit from the aquifer to the ground surface. Water wells may be dug or drilled and can be used for water supply, for aquifer tests, for measuring water levels, and for monitoring water quality.

Water wells must be designed to produce acceptable quality water and protect it from contamination. All wells constructed in the state of Idaho since 1968 have been subject to well construction standards to guard against waste and contamination of ground water resources. Steel or PVC plastic well *casing*, gravel packs, and grouting are used to isolate the pumping interval and prevent movement between different aquifers in the same area (Figure 4-8). An abandoned well should be sealed to prevent the well from being a vertical channel for contamination.

When a well is pumped the water level in the well begins to decline. The difference between the water level in a well before pumping and the water level in the well during pumping is called *drawdown* (Figure 4-9). The water table declines around the well as drawdown occurs in an unconfined aquifer. A confined aquifer experiences a drawdown in artesian pressure (loss of head) as a result of pumping, but the aquifer is not necessarily *dewatered*.

As drawdown occurs, the head in the well falls below the level in the surrounding aquifer, and water begins to flow into the well from all directions (Figure 4-9). The flow of water into a well causes a lowering of the water table in all directions, which is called a *cone of depression* (Figure 4-10). The outer limit of the cone of depression is the *radius of influence*. The *zone of contribution* is the area of the aquifer that supplies water to the well. The sizes of the cone of depression and zone of contribution depend on the hydrologic characteristics of the aquifer and the pumping rate of the well.

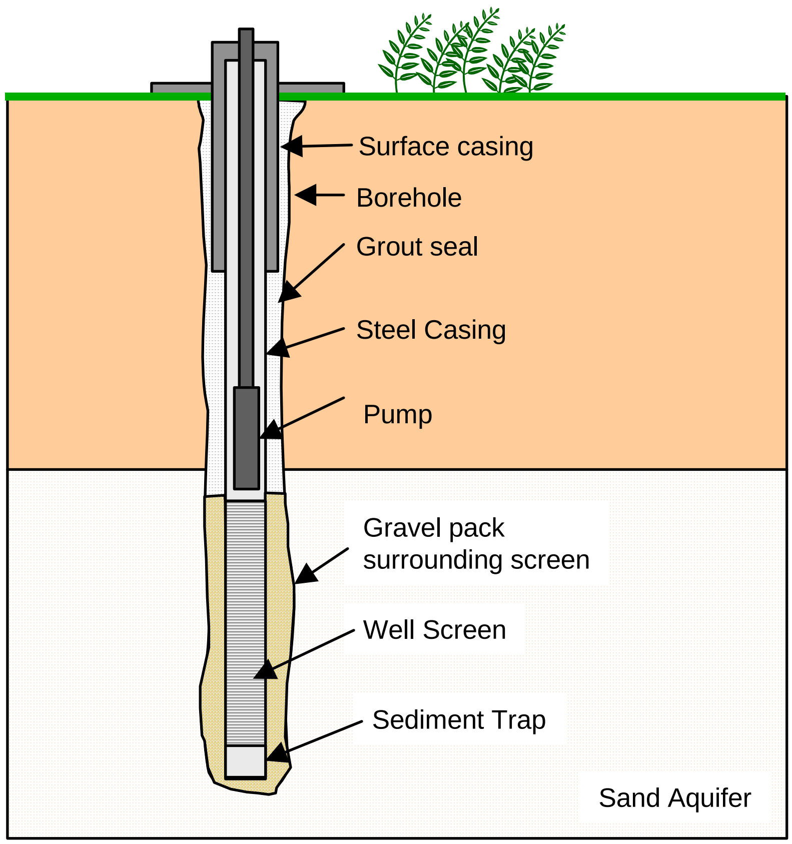

Figure 4-8: Basic well construction

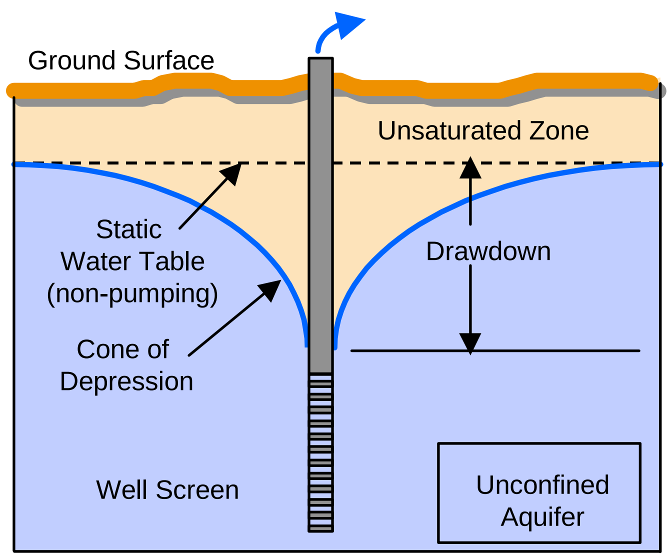

Figure 4-9. Drawdown in an unconfined aquifer

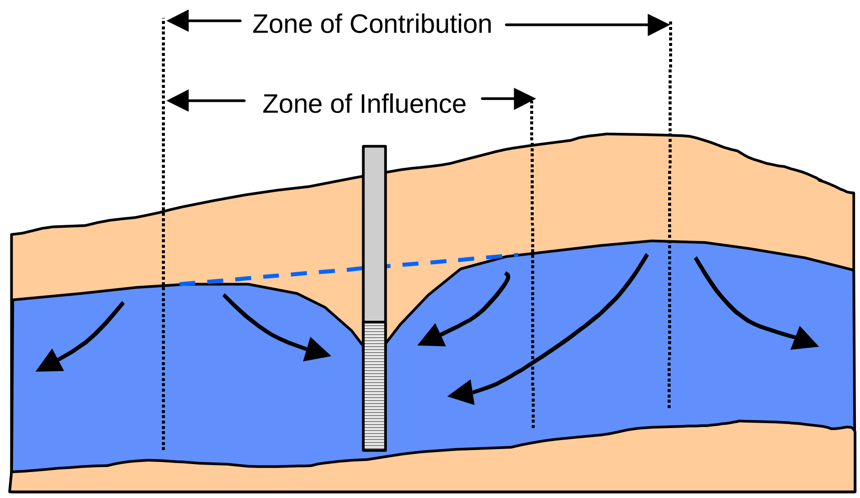

Figure 4-10. Zone of influence and zone of contribution around a pumping well.

The drawdown is proportional to the pumping rate and the length of time that pumping has been in progress. Pumping a well at a high rate typically causes a steep cone of depression. A lower pumping rate results in a shallower cone of depression. Each aquifer has a maximum sustainable pumping rate, beyond which the aquifer cannot yield sufficient water to the well.

Two or more wells pumping from the same aquifer are called a *wellfield.* Where pumping wells are relatively close together, pumping of one will cause drawdown in the others.

Drawdowns are additive, so the total drawdown in a well is equal to its own drawdown plus the drawdowns at its location caused by other pumping wells. The drawdown in one well caused by other pumping wells is called well *interference* (Figure 4-11).

4.5. Natural Ground Water Chemistry

Natural waters are never pure. They always contain at least small amounts of dissolved gases and solids. Ground water usually contains more dissolved solids than surface water. The natural chemical constituents dissolved in ground water are a function of the types of rock and soil that the ground water has contacted, the amount of time the water has been in contact with the rock or soil, the temperature and pH of the water, and other factors.

Calcium, magnesium, chloride, fluoride, iron, sodium sulfate, carbonate, and bicarbonate are common natural inorganic constituents of ground water. In low quantities, these constituents do not seriously affect the quality of ground water. In higher quantities, these constituents, as well as other inorganic and organic chemicals, may threaten the quality of our drinking water.

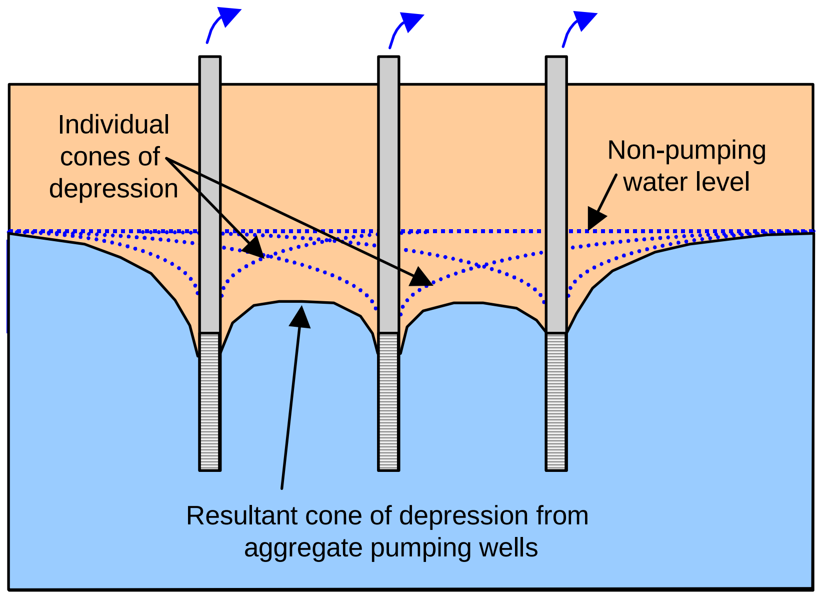

Figure 4-11. Well field interference

5. The Water Balance

A *water balance* is a tool for evaluating the hydrology of a basin. A water balance can be used for estimating seasonal or geographic patterns of irrigation or municipal water demand, the prediction of streamflow, the analysis of ground water recharge, or the analysis of ground water levels.

A water balance is the balance between the inflow and outflows of water in an area (Figure 5-1). The area can be a regional watershed, a soil profile, a regional aquifer, or a local aquifer. Inflows include precipitation, surface water flowing in from adjoining areas, or ground water underflow from adjoining areas. Outflows include water lost to evaporation and transpiration, ground water underflow to adjoining areas, surface water leaving the area, ground water discharge to rivers or drains, or ground water withdrawal (pumpage).

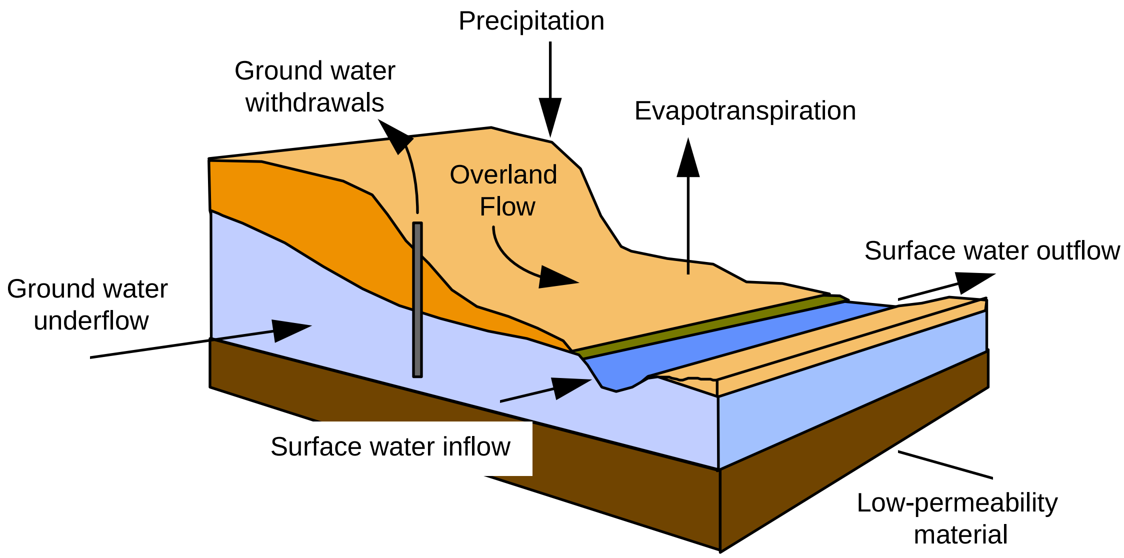

Figure 5-1: Water balance components.

Precipitation is measured at a point in a rain gauge located at a local weather station. Information from single or several gauges (if available) is then used to estimate precipitation over an area. Ground water underflow can be estimated using ground water flow equations, water level measurement data, and knowledge of the aquifer system. Surface water inflows and outflows can be estimated using stream flow estimates over a period of time. Ground water withdrawal data can be obtained from well owners (if pumping records are kept), or can be estimated on the basis of electrical consumption data, demand (such as crop demand), or numbers of people served and average per capita consumption data (for municipal suppliers). Evapotranspiration can be estimated using various climatic and vegetation data.

The water balance for this area can be described with the equation

$$P + GW_{in} + SW_{in} = GW_{\mathrm{out}} + Sw_{out} + Q + \Delta S,$$ where

P = precipitation
GW_{in} = ground water inflow
SW_{in} = surface water inflow
GW_{out} = ground water outflow
Sw_{out} = surface water inflow
Q = withdrawals (pumpage)
ΔS = net increase or decrease in water storage.

6. Summary

The material presented in this document represents a very brief and selected overview of a large and complex field. This introduction is meant to help you gain a basic understanding of some of the hydrologic issues underlying potential water disputes. There are many references with extensive additional information on all of the topics covered in this booklet; a few of these are listed in the bibliography.

7. Glossary

Alluvium. Sediments laid down by physical processes in river channels, floodplains, and fans at the foot of mountain slopes.

Aquiclude. A saturated rock unit with low hydraulic conductivity that impedes ground water flow.

Aquifer. A water-bearing rock unit that will yield water in a usable quantity to a well or spring.

Artesian aquifer. See confined aquifer.

Artesian well. A well tapping a confined aquifer in which the static water level is above the ground surface.

Basalt. A fine-grained, dark-colored volcanic rock, composed mainly of magnesium and iron-rich minerals.

Basement rocks. Igneous or metamorphic rocks that underlie stratified sedimentary rocks.

Bedrock. Consolidated (solid) rock that underlies soil or other unconsolidated material.

Bore hole. An uncased drilled hole.

Capillary forces. The forces acting on soil moisture in the unsaturated zone, due to molecular attraction between soil particles and water.

Capillary fringe. The zone directly above the water table in which water is held by surface tension.

Casing. A solid piece of pipe, typically PVC plastic or steel, used to keep a well open in unconsolidated sediments or unstable rock.

Coliform bacteria. A group of several types of bacteria, used as an indicator of fecal material in water or soil.

Cone of depression. The depression of the water table in an unconfined aquifer, or the depression of the piezometric surface in a confined aquifer, around a pumping well as a result of water withdrawal.

Confined aquifer. An aquifer, bounded by confining beds, that contains water that is under pressure significantly greater than atmospheric.

Confining layer. A layer of rock, with a very low hydraulic conductivity, which impedes movement of water into and out of an aquifer. Most confining layers are "leaky".

Contaminant. Any chemical, ion, radionuclide, synthetic organic compound, microorganism, waste, or other substance that does not occur naturally in ground water or that occurs naturally at a lower concentration.

Crystalline rock. A rock consisting wholly of crystals or fragments of crystals. Usually refers to igneous or metamorphic rocks.

Darcy's Law. An equation used to calculate the quantity of ground water flowing through an aquifer.

Discharge area. The area in which ground water moves upward, toward the water table and may escape as a spring, seep, or surface stream, or may evaporate.

Domestic withdrawals. Water used for normal household purposes.

Drawdown. The difference between the water level in a well before pumping and the water level in the well during pumping.

Dry well. A well that does not extend into the saturated zone.

Evapotranspiration. The combined processes of evaporation and transpiration.

Ground water. Water present beneath the earth's surface.

Ground water divide. A ridge in the water table or potentiometric surface, from which water moves in two opposite directions.

Head. The height to which water will rise in a well, a function of pressure and elevation.

Headgate. A device for controlling flow in a canal or into a diversion.

Hydraulic conductivity (K). The capacity of rocks or sediments to transmit water, usually measured in ft/day or cm/sec. Determined by the size and shape of pore spaces in the material, the degree of interconnection of pores, and by the viscosity of the fluid.

Hydraulic gradient. The difference in head per unit distance.

Infiltration. The movement of water into soil or porous rock.

Joints. Fractures in rock, in which movement has been perpendicular to the fracture plain. Joints form in basalt as it cools and in granite and sedimentary rocks.

Lithology. The description of rocks or sediments on the basis of common characteristics, or the physical character of rocks.

Local flow system. Small-scale systems of ground water flow within a larger regional flow system.

Loess. A widespread, fine grained blanket of wind-deposited silt, clay, and fine sand.

Maximum Contaminant levels (MCL). Health-based standards established by the state and federal government (Environmental Protection Agency, 1990).

Metamorphic rock. Any rock formed by the alteration of pre-existing rocks, as a result of heat, pressure, or chemical activity deep within the earth.

Metasediment. A sedimentary rock that shows signs of having undergone metamorphism.

mg/L. Milligrams of solute per liter of solution. Unit of measurement of dissolved constituents in water:

Monitoring well. A well used to measure ground water levels and to obtain water samples for chemical analysis.

Outwash. Sediments removed or "washed out" from a glacier by meltwater streams and deposited beyond the margin of an active glacier.

Overland flow. Water flow on the ground. Occurs when precipitation rates exceed infiltration capacity of a soil.

Percolation. The slow movement of water through pore spaces in soil, sediment or rock.

Plume. A body of contaminated ground water that migrates from a point or nonpoint pollution source.

Point Source Pollution. Pollution resulting from any confined, discrete source, such as a pipe, ditch, well, container, concentrated animal feeding operation, etc.

Porosity. The percentage of rock or soil that is void of solid material. The ratio of void space to the total volume of rock or sediment. Effective porosity is the volume of the connected void spaces through which water or other fluids can travel divided by the total volume of rock or sediment.

Potable water. Water that is safe for human consumption.

Potentiometric surface. The surface defined by levels to which ground water will rise in tightly cased wells that tap an artesian aquifer. (also known as piezometric surface)

Pressure head. Hydrostatic pressure (force per unit area) expressed as the height of a column of water hat the pressure can support.

Pumping test. A test made by pumping water from a well and observing the change in hydraulic head in the aquifer.

Quaternary. The second period of the Cenozoic era. It began two to three millions years ago and extends to the present, encompassing the Pleistocene and Holocene epochs.

Recharge. The addition of water to the ground water system by natural or artificial processes.

Recharge area. An area over which recharge occurs.

Remediation. The process of cleaning a contaminated area, to restore or improve the quality of ground water.

Runoff. The portion of precipitation that flows on the surface of the earth in lakes, streams or overland flow.

Saline water. Water that is unsuitable for human consumption or for irrigation because of high amounts dissolved solids.

Saturated zone. The area underground in which all voids in the rock or sediment are filled with water.

Sediments. Assemblages of individual rock grains deposited by wind, water, ice or gravity.

Sedimentary rocks: Rocks formed by the accumulation, compaction and lithification of sediment.

Soil. Unconsolidated natural materials, near the earth's surface, which support plant life and are typically organic-rich.

Sole source aquifer. An aquifer designated by the EPA as the "sole" water supply source in an area. The aquifer must be the principal source of water and supply 50% or more of the drinking water for the area. The Rathdrum Prairie aquifer and the Eastern Snake River Plain aquifers are sole source aquifers.

Storativity. The volume of water that an aquifer will release from storage per unit surface area per unit decline in head.

Stratigraphic layer (stratum). A layer of sedimentary rock, visibly separable from layers above and below.

Surface water. Water that resides in lakes, rivers or oceans on the surface of the earth.

Transmissivity. The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. (Transmissivity is defined as the hydraulic conductivity of an aquifer multiplied by the aquifer thickness.)

Transpiration. The process by which plants release water into the atmosphere.

Turbidity. The reduced clarity of water due to suspended solids.

Unconfined aquifer. An aquifer whose upper surface is the water table. Also called a "water table aquifer", the upper surface can fluctuate seasonally.

Unsaturated zone. The area, below ground surface and above the water table, in which pores between rock and sediment are filled with both water and air.

Urban runoff. Water from rain and snow that lands in populated areas and travels through storm sewers or other systems, and typically contains nitrates, lead, salts and other chemicals associated with urban environments.

Vesicles. Small openings in basalt, caused by gas bubbles that escape as basalt cools. Vesicles contribute to the porosity of basalts.

Weir. Structure for regulating flow in canals.

Well field. Two or more wells pumping from the same aquifer.

Well interference. The cumulative effect of pumping two or more wells whose drawdown cones intercept. The total well interference at a given location is the sum of the drawdowns due to each individual well.

Well. An artificial excavation or opening in the ground by which water is sought or obtained.

Zone of contribution. The area surrounding a well from which water is drawn into the well during pumping.

Zone of influence. The area surrounding a well in which drawdown of the aquifer occurs during pumping. The outer limits of the cone of depression define the zone of influence.

8. Units and Unit Conversions

1 cubic foot of water = 7.4805 gallons = 62.37 pounds of water

1 cubic foot per second (cfs) = 448.83 gallons per minute (gpm) = 26930 gallons per hour

1 cubic foot per second = 646,635 gallons per day = 1.935 acre-feet per day

1 cubic foot per second for 30 days = 59.502 acre-feet

1 cubic second for 1 year = 723.94 acre-feet

1 acre-foot = enough water to cover 1 acre of land 1 foot deep.

1 acre-foot = 43,560 cubic feet

1 acre-foot = 325,850 gallons

1 cubic meter per second (cms) = 25.31 cubic feet per second

1 cubic meter per second – 15,850 gallons per minute

1 million gallons = 3.0689 acre-feet

1 million gallons per day (mgd) = 1,120.147 acre-feet per year

$0.10 per 1,000 gallons = $32.59 per acre-foot.

1 miner's inch = 9 gallons per minute

1 miner' inch = 0.02 cubic feet per second

ppb--parts per billion (mass of solute per 1,000,000,000 mass units of solution.)

ppm--parts per million (mass of solute per 1,000,000 mass units of solution.)

9. Bibliography

Aisenbrey, Jr., A. J., R. B. hayes, H. J. Warren., D. L. Winsett, and R. B. Young. 1974. Design of Small Canal Structures. U.S. Department of the Interior, Bureau of Reclamation. Denver.

Bates, Robert Latimer and Jackson, Julia A., 1987, Glossary of Geology, American Geological Institute, Alexandria, VA, 788 p.

Dingman, S. L. 1994. Physical Hydrology. McMillan Publishing Co., New York. 575 p.

Domenico, Patrick A., and Schwartz, Franklin W., Physical and Chemical Hydrogeology, 1990, John Wiley & Sons, Inc., New York, NY, 824 p.

Driscoll, . G. 1986. Groundwater and Wells. Johnson Division, Minneapolis, Minnesota.

Fetter, C.W., 1988, Merrill Publishing Company, Columbus, OH, 592 p.

Freeze, R. Allan and Cherry, John A., 1979, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, NJ, 604 p.

Harlan, R.L., Kolm, K.E., and Gutentag, E.D., 1989, Water Well Design and Construction, Elsevier Publishers, 205 pp.

Heath, Ralph C., 1982, Basic Ground-Water Hydrology, U.S. Geological Survey Water Supply Paper 2220, 84 p.