I. GROUNDWATER OCCURRENCE AND PROCESSES

A. Introduction

1. Water contained within cracks, fractures and pore spaces of soil, sediment and rocks beneath the surface of the earth

2. Groundwater is much more voluminous and ubiquitous than surface water, commonly found within 2500 feet depth below land surface.

3. Groundwater flow path: atmospheric precipitation percolates into soil/bedrock directly or from surface lakes and streams, and generally flows downward under the force of gravity until it reaches some sort of physical barrier or impermeable zone, which either severely impedes flow or stops it altogether.

4. Types of Groundwater

a. Meteoric Water: water recently circulated from atmospheric cycle

b. Connate Water: water that is entrapped with sediments when they are deposited, and subsequently gets buried and lithified with the sediments in form of sedimentary rock.

(1) I.e. connate water = fossil water.

c. Juvenile Water: water freshly derived from deep within the interior of the earth via volcanic processes.

B. Groundwater Hydraulic Mechanisms

1. Porosity: ratio, in per cent, of the volume of void space to the total volume of sediment or rock

$$P (\%) = \frac{\text{total volume - volume of solids}}{\text{total volume}} \times 100$$

a. Porosity is the primary governing factor influencing the ability of rock or sediment to store fluids (e.g. groundwater or hydrocarbons)

b. Types of Porous Openings

(a) Intergranular Porosity = primary pore spaces present between particles of a sediment or rock deposit

i) Intergranular Porosity influenced by:
        a) sorting
        b) grain packing
        c) grain size
(b) Fractured Porosity
(c) Solution Cavities
(d) Vesicles

c. Effective porosity: considers the extent to which pore spaces are interconnected in a deposit, as well as the force of hydrostatic attraction that binds water molecules to the surfaces of grains/pore spaces
    (1) Hygroscopic Water = high suface tension of water creates tendancy to coat pores with electrostatically-bound film of water

        (a) effectively reduces porosity of rock/material

d. Secondary Porosity: can impart a secondary or "overprint" porosity on a rock unit via structural fracturing and chemical dissolution.

e. Lithologic Control on Porosity
    (1) Porosity of Unconsolidated Sediments
        (a) function of grain size and packing
            i) uncompacted clay and silt = very high porosity (up to 50%)
                a) compacted clay and silt = decreased porosity to 15%
            ii) sand and gravel: porosity of 20-30% typically

    (2) Porosity of Sedimentary Rocks
        (a) Primary vs. Secondary Porosity
        (b) Sandstone and conglomerate may possess relatively high porosities (30%)
        (c) Limestone and carbonates may be low or high depending on solution
            i) dissolved limestone ---- high secondary porosity
            ii) hard, dense limestone ----- low primary porosity

    (3) Porosity of Crystalline Plutonic and Metamorphic Rocks
        (a) Very low primary porosity
        (b) Secondary "structural porosity"
            i) joints, fractures, faults -----porous zones
                a) may achieve 5-10% on avg, up to 50% porosity in some instances

    (4) Porosity of Volcanic Rock
        (a) Vesicles and columnar jointing may create relatively high porosities
        (b) Inter-flow fluvial deposits
        (c) brecciated horizons

2. Permeability: the degree of interconnectedness between pore spaces and fractures within a rock or sediment deposit. A measure of the capacity of a porous material to transmit fluids

a. Permeability (K) is largely a function of:
  (1) grain size, size of pore space
  (2) shape of grains/shape of pore space
  (3) degree of interconnected pore space

b. Hydraulic Conductivity = permeability in a horizontal direction in aquifer

  (1) Measure of rate of tranmission of fluids horizontally through aquifer, essentially another term for permeability (modification of Darcy's Law)

$Q = KIA$ Where Q = discharge (L^3/T)
                      K = hydraulic conductivity (permeability) (L/T)
                      I = hydraulic gradient (vertical head distance between two points of observation) (decimal ratio)
                      A = cross-sectional area through which flow occurs (L^2)

    (a) Vertical Conductivity = capacity to transmit fluids in vertical direction

    (b) Horizontal Conductivity = capacity to transmit fluids in horizontal direction

c. Darcy's Law

  $$Q = \frac{KA(P_2-P_1)}{uL} \quad \text{where,}$$

        Q = Volume Discharge Rate (cm^3/sec)
        K = Permeability (millidarcy = mD)
        A = Cross-sectional area at perpendicular
                to flow (cm^2)
        L = length along which press. diff. is
                measured (cm)
        (P_2-P_1)= pressure difference (atm) between
                        two points separated by distance L
        u = viscosity of fluid (centipoises)

Generally, well sorted sand and gravel display high porosity and permeability, however, a poor sorted sand with much matrix material will have a low permeability.

Unpacked clay, may have a very high porosity but very low permeability.

Generally clay/shale make for good permeability barriers, while sand and gravel readily transmit fluids. However secondary overprints such as structural deformation and diagenetic alteration (post-depositional changes in mineralogy) can drastically influence permeabiltiy and porosity.

    d. Specific Yield and Specific Retention

    (1) Specific Yield of Aquifer

(a) S.Y. = <u>Vol. of Water Drained Under Gravity</u>
Total Volume of Rock in Aquifer

(2) Specific Retention
(a) S.R. = <u>Vol. of Water Retained as Water Film</u>
Total Volume of Rock in Aquifer

e. Permeability Vs. Lithology
(1) Permeability of Unconsolidated Sediments
(a) Relationships to Grain Size
i) Perm < with < Grain Size (and vice versa)
ii) Perm < with < sorting (and vice versa)

a) Hence well sorted corase sediment (sand, gravel) display the highest permeability

b) Poorly sorted or very fine sediment (clayey sand, or clay) generally display lowest permeability

(2) Permeability of Lithified Rocks
(a) Function of interconnected nature of pore spaces
i) Sandstone, Conglomerate = high primary permeability
ii) Limestone = low primary permeability
a) Dissolved Limestone ----- high secondary permeability
iii) Shale and Well-cemented Siltstone = low primary permeability
a) Fractured Shales and Siltstones = high secondary permeability
iv) Crystalline Igneous and Metamorphic Rocks = low primary permeabiltiy
v) Fractured Shales and Siltstones = high fractured (secondary permeability
vi) Volcanic Rocks = high primary permeability associated with columnar jointing

C. Subsurface Hydrologic Zones
1. Zone of Aeration or Vadose Zone:
2. the uppermost portion of the groundwater environment, extends from a few cm's to hundreds of meters.
(1) Zone contains mixture of moisture and air held in pore spaces by molecular attraction.
(2) Much water flows downward through this zone into the underlying layer.

3. Zone of Saturation: or phreatic zone: zone below zone of aeration, in which all pore spaces, fractures and cracks are filled or saturated with water. (i.e. groundwater).

a. Water table: the top surface of the saturated zone, open to atmospheric pressure conditions via the vadose zone above.

b. Ground water flow: groundwater flows along permeable zones under the force of gravity, taking the path of least resistance. Ground water flows along porous paths from areas of higher water table elevation to areas of lower water table elevation.

c. Water table configuration: water table generally follows the surface topography of the land above, rising to higher elevations beneath hills, and lower elevations beneath valleys, generally water table deeper beneath hills, and coming closer to surface beneath valleys.

(1) intersection of water table with surface of the earth results in surface flow of water in form of springs or seeps, or perhaps manifested as a lake or swamp.

d. Pressure Relationships: the level of the water table is generally a surface of constant pressure or hydrologic head.

(1) A well dug to intersect the water table, will fill with water to the level of the water table, unless under some kind of hydrostatic pressure (artesian conditions)

(2) Groundwater Maps: elevations of top of water table can be mapped and contoured

i) Ground water elevations derived from measuring water levels in wells

(a) Hydraulic Gradient = rise/run or slope of water surface = (vertical difference/horizontal distance)

a) Groundwater flow generally parallel to lines of gradient (i.e. perpendicular to contour lines in downgradient direction under force of gravity)

(3) Cone of depression- if water is pumped from a well faster than it can be replaced, the level of the water table will be drawn down in the shape of an inverted cone.

D. Aquifer Types

1. Definitions

a. Aquifer: porous rock/sediment units that have a capacity to contain water, pores can be formed by openings between grains (primary porosity) or by cracks and fractures in the rocks (secondary porosity)

(1) Common Aquifers: unconsolidated sand and gravel, sandstone, dissolved/fractured limestone, lava flows, fractured crystalline rocks.

b. Aquiclude: Impermeable layers which will not transmit or store groundwater, tend to form the upper or lower boundaries of aquifers

c. Aquitard = "leaky" aquiclude: low permeability layers which transmit groundwater at very slow rates in both vertical and/or horizontal directions.
(1) More permeable than aquiclude

d. Aquifuge: effectively impermeable body of rock or unconsolidated material

2. Unconfined Aquifers: aquifers in vertical and hydraulic continuity with land surface.

    a. Water Table Aquifers = Unconfined Aquifers
        (1) Water of saturated zone in open contact with atmopheric pressures
        (2) Water percolates through vadose zone to phreatic zone
        (3) Capillary Zone: layer immediately above water table where water moves upward under high surface tension and capillary forces

3. Confined Aquifers: aquifers that are separated from atmospheric pressures by impermeable zones or confing layers (water not referred to as "water table")

    a. Confined aquifer and artesian conditions, relative to hydrostatic pressure

        (1) Potentiometric surface: analogous to water table, but is elevation of water of confined aquifer that rises to equilibrium in open well penetrating confined aquifer

            (a) may contour elevations to form potentiometric contour map

                i) confined aquifer groundwater flow generally perpendicular to contour of potentiometric surface.

            (b) confined aquifers commonly under hydrostatic pressure in response to rock compaction and pore fluid pressures

    b. Artesian Aquifer: identified as water in a well that rises under pressure above the saturated confined aquifer horizon

        (1) Conditions of formation:
            (a) confined aquifer between two impermeable layers
            (b) exposure of aquifer to allow recharge/infiltration
            (c) hydraulic flux into the aquifer from water cycle

    c. Free-flowing artesian aquifer
        (1) Artesian aquifer in which pressures are such that water freely flows out onto the ground surface.

    d. Perched Aquifers: localized zone of upper level groundwater occurrence "perched" above a laterally discontinous aquitard.

        (1) forms a localized occurrence of groundwater above regional water table system (hybrid of confined and unconfined systems)

E. Groundwater and Environmental Concerns

    1. Resource Development

        a. Groundwater use for urban and domestic needs prevalent throughout North America

        (1) Residential use in rural areas off "plumbing grid" of public water supplies
        (2) Residential and Industrial use in arid and semi-arid portions of U.S.
          (a) Groundwater useage very prevalent throughout the Mid-west and Far-west.

2. Environmental Hazards
   a. Groundwater Contamination
        (1) Industrial/Government Facilities
        (2) Sewage/bacteria
        (3) Mining
        (4) Landfills

   b. Ground Subsidence and Subsurface Fluid Withdrawal
        (1) Extensive withdrawal of subsurface fluids
          (a) groundwater
          (b) Petroleum

3. Fluid withdrawal results in decrease in pore pressure, leading to subsidence of land areas under lithostatic pressure