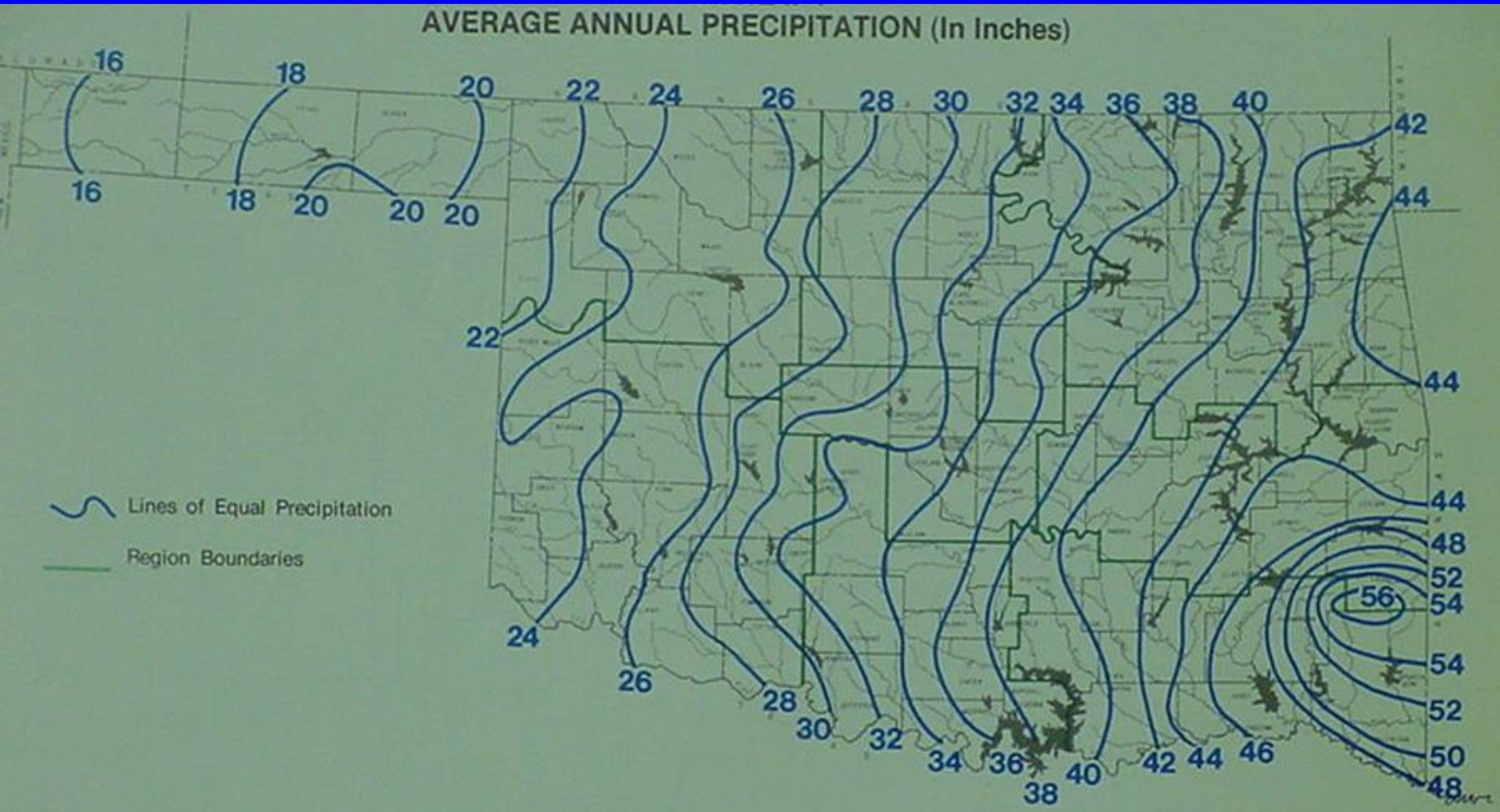
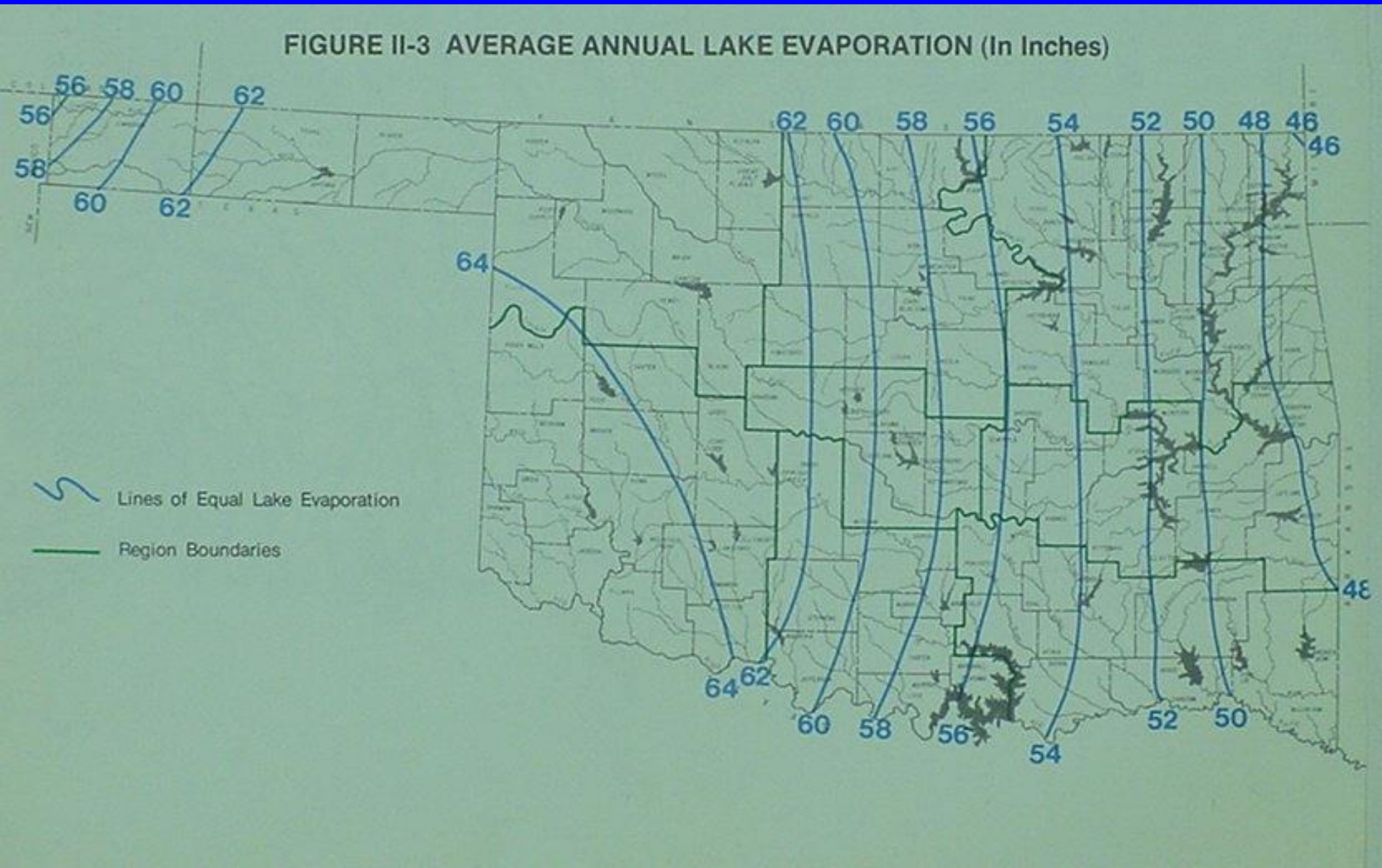
Surface Water

- Streams and rivers
  - diversion by gravity flow or pumping
  - often low flows when irrigation water is needed most
- Lakes, ponds, reservoirs
  - gravity flow or pumping
  - source of water need for replenishing

Average Annual Precipitation in Oklahoma

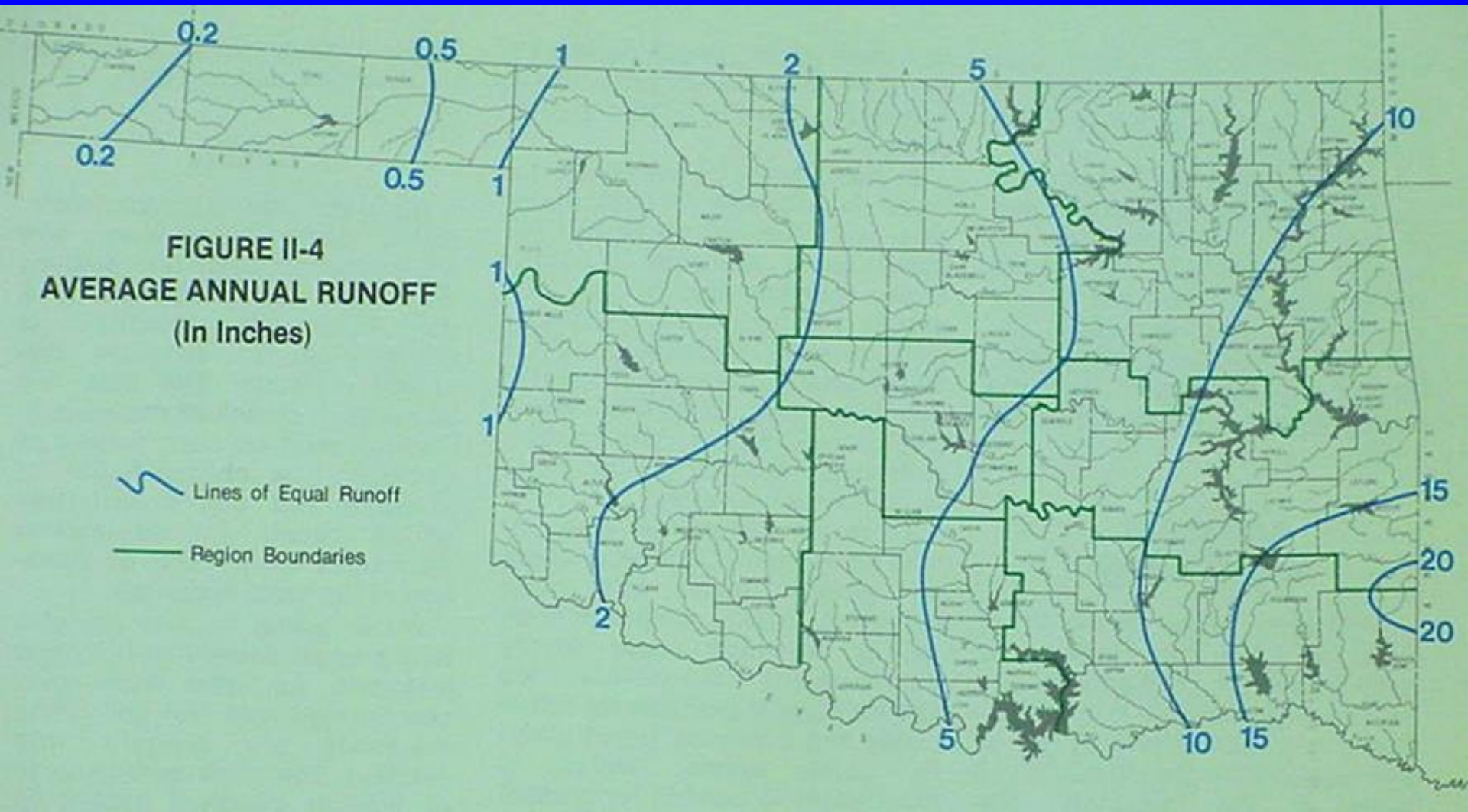


Annual Evaporation from Free Water Surfaces



Average Annual Runoff from Watersheds

(acre-inches of runoff/acre of watershed)



Hydrologic Considerations

- Panhandle Calculation (Guymon, OK)
  - Rainfall: 18 in/year
  - Evaporation: 63 in/year
  - Runoff: 0.3 acre-inch/acre
- Loss: 63”-18”= 45 acre-in per acre of lake
- Gain: 0.3 acre-in per acre of watershed
- Need: 45/0.3 = 150 acres of watershed per acre of lake (just to offset evaporation loss)

Ground Water Storage

- Underground lakes & rivers? No!
- Pore spaces between individual particles (sand and gravel)
- Fractures in hard rock
- Porous sandstone
- Solution channels or caverns in limestone or gypsum (nearly underground rivers)

Ground Water Movement

- Movement rate is typically tenths of a foot per day up to a few feet per day
- Rate is dependent on:
  - the size and number of openings (pore spaces, fractures, solution channels)
  - the amount of water pressure created by differences in water levels

Ground Water Terminology

- Porosity: percentage of a geologic formation that consists of open spaces (same as soil porosity)
- Specific yield: percentage of a formation that is occupied by water which will drain out by gravity
- Specific retention: percentage of the formation that is occupied by water which is retained against gravity
- Specific retention + Specific yield = Porosity
- Permeability: property of formations indicating how rapidly water will be transmitted (high in sands and gravels; low in clays)

Ground Water Terminology 2

- Saturated zones: portions of a soil profile or geologic formation where all spaces or voids are filled with water (no air is present)
- Unsaturated zones: soil and geologic materials located between the land surface and the saturated zone (spaces or voids are filled with combination of air/water)
- Water table: level in a formation below which all spaces or voids are filled with water (top of the saturated zone)

Ground Water Terminology 3

- Aquifer: saturated formation that will yield usable quantities of water to a well or spring
- Unconfined aquifer (water table aquifer): aquifer whose upper water surface is the water table (no layers restricting water movement into the saturated zone from above)
- Confined aquifer (artesian aquifer): aquifer in which the water is confined under pressure between low-permeability materials (aquitards)

Confined and Unconfined Aquifers

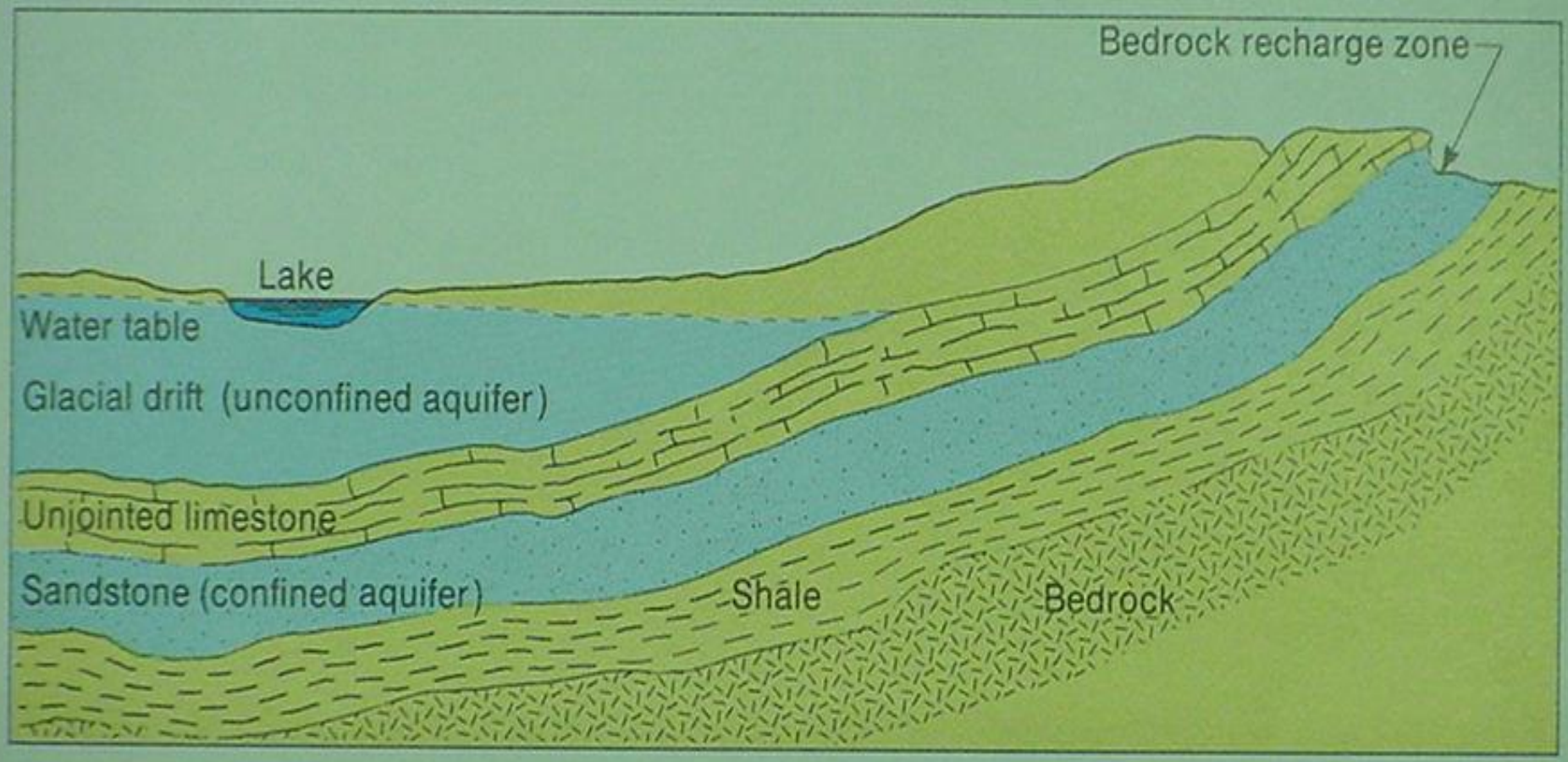


Figure 5.2. Groundwater exists in the underground in two major environments: unconfined and confined.

Well Drilling

- Dug wells: dug by hand or backhoe equipment
- Driven Wells: sand point wells are driven with a sledge hammer or post driver
- Dug & Driven wells are shallow, low yielding wells
- **Professionally Drilled Wells**
- Cable-tool percussion wells: a heavy bit is repeatedly lifted and dropped to loosen and break-up formation
  - particles are periodically removed with a bailer
  - effective for formations containing rocks and boulders
  - generally for wells 12 inches in diameter or less

Well Drilling 2

- Rotary: rotating bit connected to a hollow drill stem through which drilling fluid is pumped
  - Drilling fluid serves several purposes
    - Cools & lubricates the drill bit
    - Removes drill cuttings
- Different rotary versions:
  - Direct rotary: fluid down stem, up the borehole
  - Reverse rotary: fluid down borehole, up drill stem
  - Air rotary: compressed air is the drilling fluid

Well Components

- Bore hole: cylindrical shaped opening created by the drilling operation
- Casing: round pipe (usually steel) that protects the bore hole from collapse and houses the pump
- Screen (intake section): manufactured screens are best, but other types of perforations are sometimes used (torch slots, saw cuts, etc.)
- Gravel pack (optional): material with greater permeability placed around intake section

Well Hydraulics Terminology

- Static water level: water level in a well when the pump is not operating (is idle for several days)
- Pumping water level: water level in a well when the pump is operating at some flow rate
- Drawdown: difference between water levels in a well under non-pumping and pumping conditions
- Cone of depression: drop in ground water levels around a well or group of wells in response to ground water withdrawal [aquifer volume that is affected by pumped well(s)]
- Lift: vertical distance from the water level in a well during pumping to some delivery point

Well Hydraulics Terminology

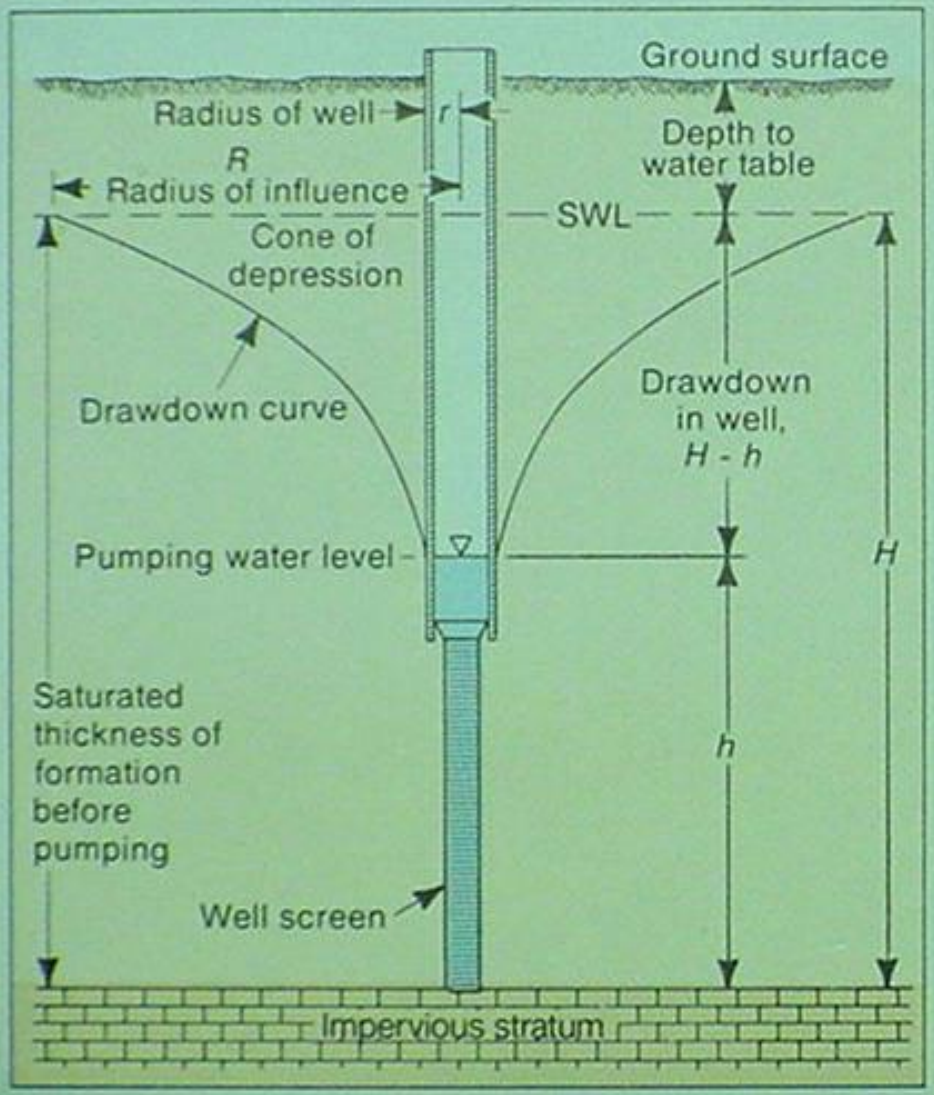


Figure 9.8. Well in an unconfined aquifer showing the meaning of the various terms used in the equilibrium equation.

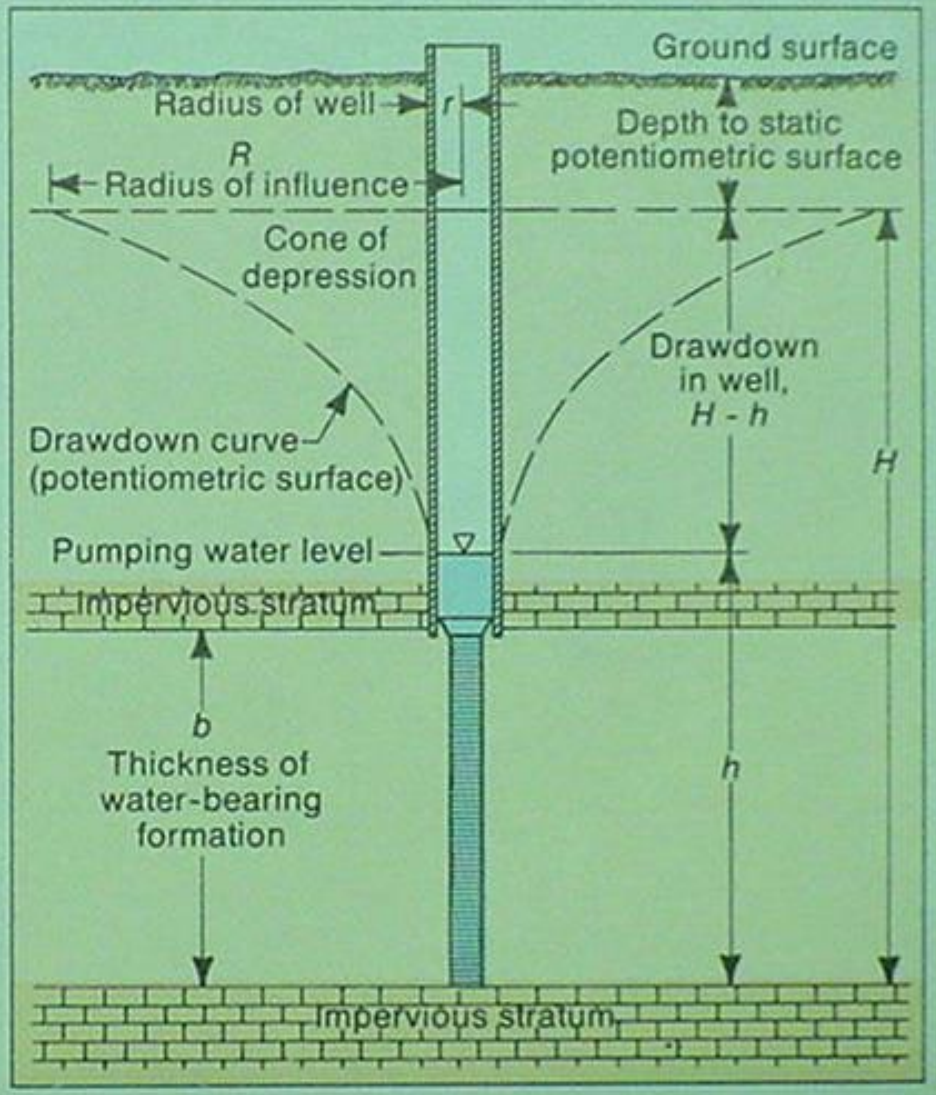


Figure 9.9. Well in a confined aquifer showing the meaning of various terms used in the equilibrium equation.

Well Yield

- Influencing factors
  - aquifer characteristics
  - strainer characteristics (screen, gravel pack, etc.)
  - well penetration depth into the aquifer
  - well diameter (doubling d results in about a 10% increase in Q)
- Yield [Q] and drawdown [H-h]
  - Interrelated (Q increases as [H-h] increases)
  - Case of diminishing returns (maximum practical Q occurs when [H-h] = 0.88H)

Test Holes

- Is a well feasible?
- Where should it be located?
- Usually rotary drilled; about 4-inch diameter
- Things you can learn:
  - depth to static water level
  - type and thickness of water-bearing formations
  - best methods for drilling and developing the well
  - recommended gravel pack, screen size, etc.

Characteristics of Aquifer Materials

Table 9.2. Approximate Characteristics of Groundwater Aquifers (adapted from Schwab et al., 1992).

Aquifer Material	Total Porosity %	Specific Yield %	Relative Permeability
Dense Limestone	5	2	1
Dense Shale	5	2	1
Sandstone	15	8	700
Gravel	25	22	5000
Sand	35	25	800
Clay	45	3	1

Hydraulic Conductivity of Aquifer Materials

Table 9.3. Range of hydraulic conductivity values for various types of aquifers (adapted from Driscoll, 1986).

Aquifer Formation or Material	Range of Hydraulic Conductivity, (ft/day)	
	low	high
Fine to Coarse Gravel	10^{1}	10^{4}
Fine to Coarse Sand	10^{-3}	10^{2}
Silt and Loess	10^{-4}	10^{0}
Glacial Till	10^{-8}	10^{0}
Karst Limestone	10^{-2}	10^{2}
Shale	10^{-9}	10^{-5}
Sandstone, well cemented, unjointed	10^{-6}	10^{-4}
Sandstone, friable	10^{-4}	10^{-1}
Unfractured igneous and metamorphic rocks	10^{-9}	10^{-6}
Fractured igneous and metamorphic rocks	10^{-4}	10^{0}

Radius of Influence in Aquifer Materials

Table 9.4. Practical Radius of Influence of Wells

Soil Formation and Texture	Radius of Influence (ft)
Fine sand formations with some clay and silt	100-300
Fine-to-medium sand formations, no clay and silt	300-600
Coarse sand and fine gravel formations free from clay and silt	600-2000
Coarse sand and gravel, no clay or silt	1000-2000

Example 9.1

Calculate the flow rate in gal/min of a well completely penetrating an unconfined aquifer. The well diameter is 12 inches, the height of the water table is 100 ft above the impervious layer and the water level in the well during pumping is 50 feet. The aquifer material consists of coarse sand and fine gravel with no appreciable amounts of clay or silt.

Given: Well diameter (2 r) = 12 in
Water table height (H) = 100 ft
Height of water in well (h) = 50 ft
Coarse sand and fine gravel aquifer

Find: Flow rate of well (q).

Solution: $$q = \frac{\pi K(H^2 - h^2)}{\ln(R/r)}$$

Hydraulic conductivity (K) values are given in Table 9.2. Since the aquifer is a mixture of sand and gravel, an approximate value of K is 50 ft/day. The units for K in the equation are ft/min.

$$K = 50 \frac{ft}{day} \frac{day}{24\ hr} \frac{hr}{60\ min}$$

$$K = 35 \times 10^{-3} \text{ ft/min}$$

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$$K = 50 \frac{ft}{day} \frac{day}{24\ hr} \frac{hr}{60\ min}$$

$$K = 35 \times 10^{-3} \text{ ft/min}$$

From Table 9.4 a value of 1000 ft was chosen for the radius of influence (R).

$$q = \frac{3.14(35x10^{-}3)\ [(100)^2 - (50)^2]}{\ln(1000/0.5)}$$

$$q = \frac{110\ x\ 10^{-}3\ [7.5\ x\ 10^3]}{7.6}$$

$$q = 108 \text{ ft}^3/\text{min}$$

$$q = 108 \frac{ft^3}{\text{min}} \frac{7.48\ gal}{ft^3}$$

$$q = 808 \text{ gal/min}$$

Gravel Pack

- Gravel pack (envelope): coarse particles placed between the aquifer material and the well screen
- Material should be rounded, silica gravel
- Gravel pack purposes:
  - keep fine sand from entering the well
  - increase permeability around the screen
  - allow larger openings in the screen

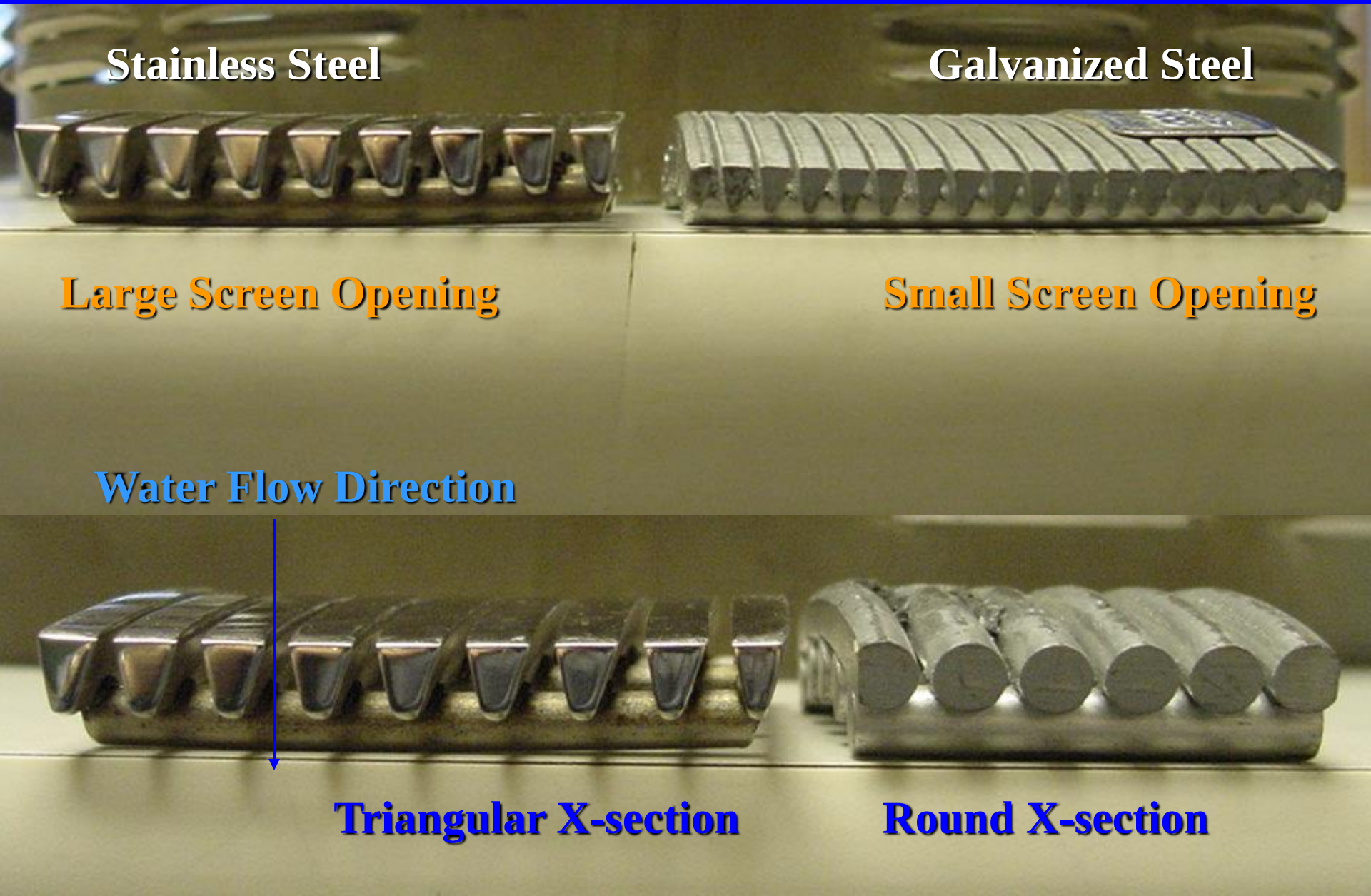
Well Screens

- Screen types
  - Home-made: torch cuts; mill/sawed slots (not good)
  - Manufactured: shutter/louver type, continuous slot (V-shaped or round wire)
- Length: depends on aquifer formations
  - Lower 1/3 of unconfined aquifer depth
  - 80-90% of confined aquifer thickness
- Slot width: size to exclude 90% of gravel pack or aquifer material (if the well is gravel packed)
- Diameter: depends on well size; also entrance velocity considerations
- Type of material: strength, corrosion, incrustation factors

Torch-cut slots in a steel casing

Torch-cut slots normally result in about 10% open area for water flow.

Manufactured Well Screens



Screen Sizes and Materials

8-inch

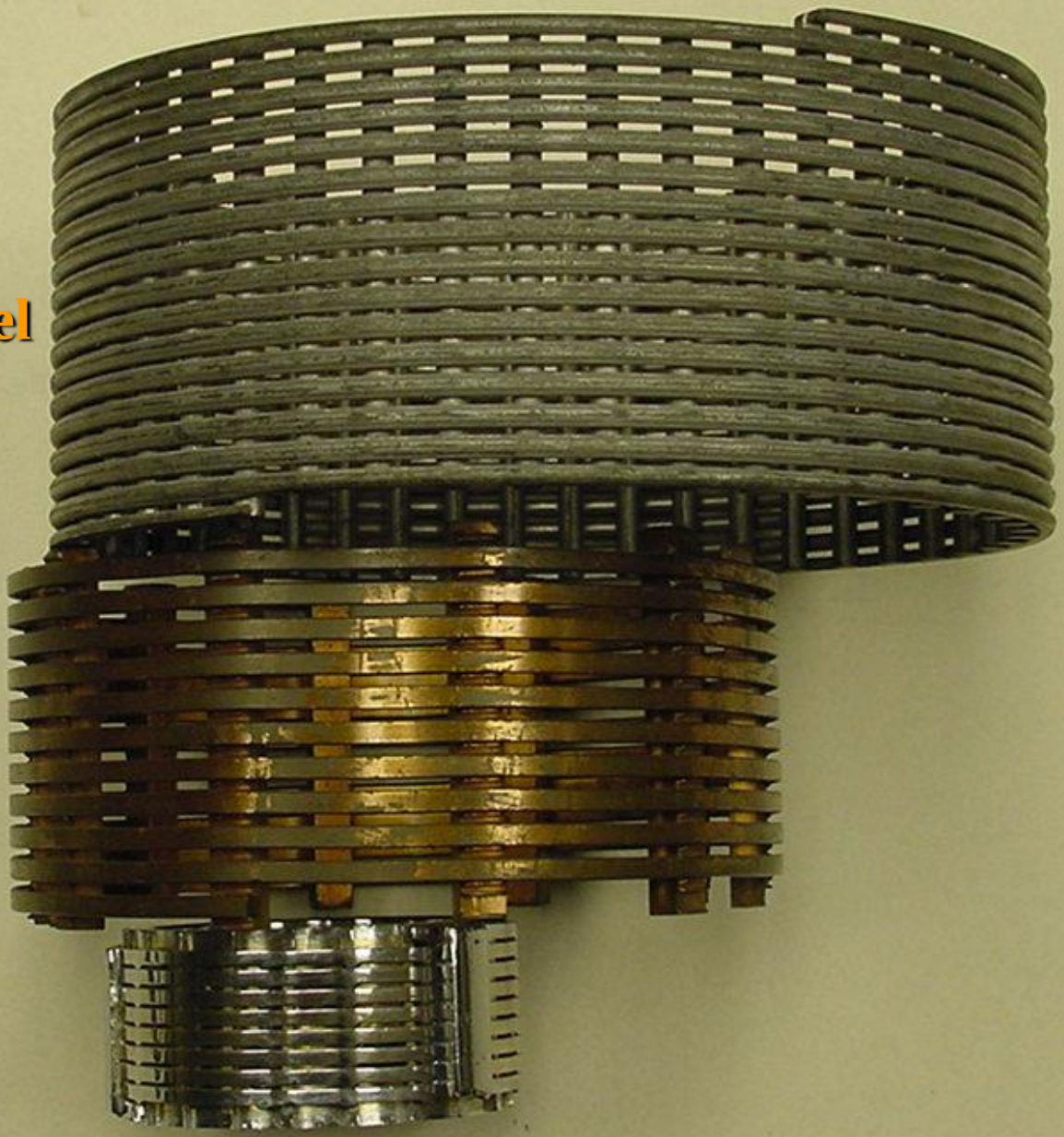
Galvanized Steel

6-inch

Bronze

4-inch

Stainless Steel



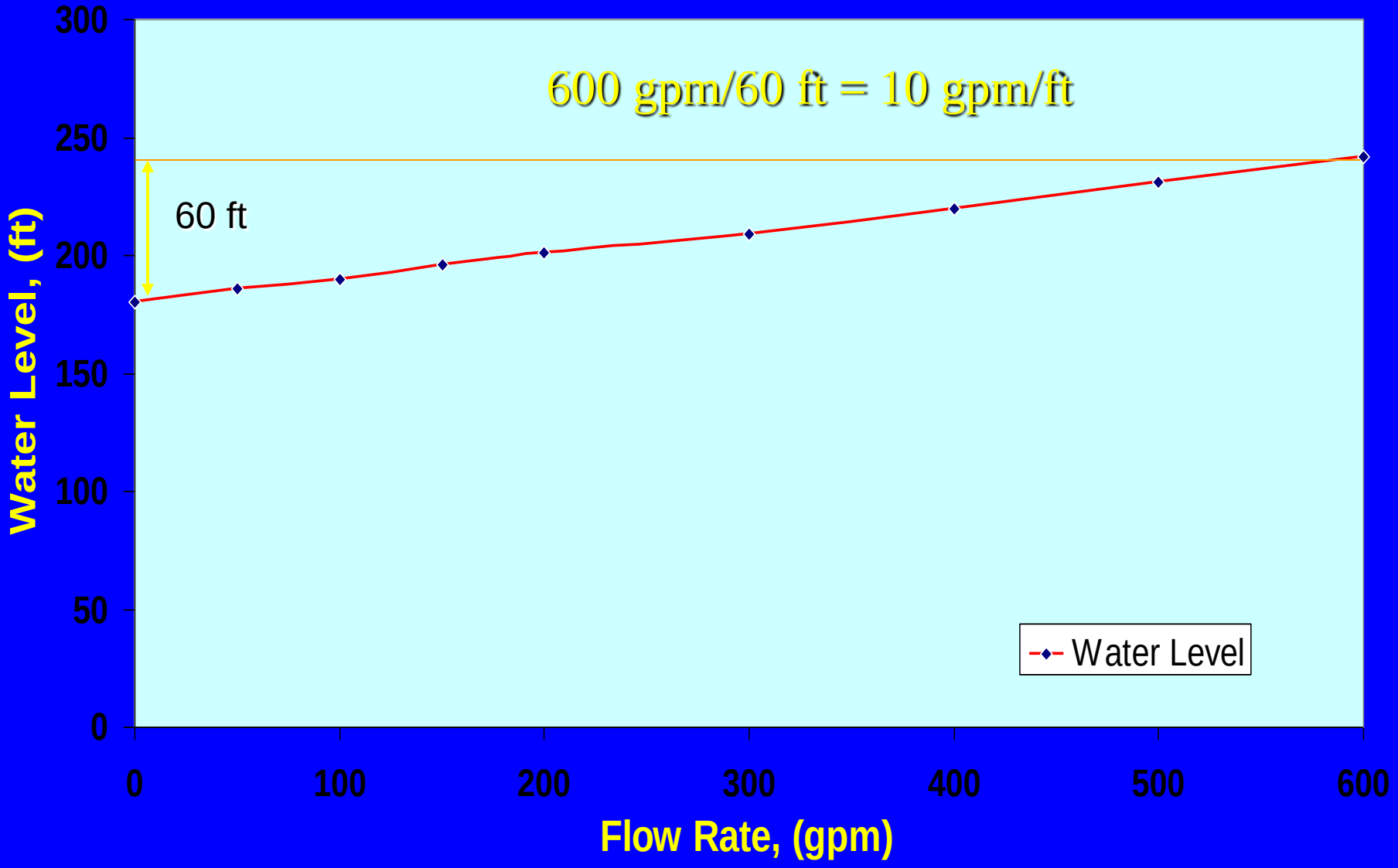
Well Development

- Purposes:
  - Remove skin resulting from drilling mud
  - Increase permeability around the well
  - Stabilize formation to minimize sand pumping
- Methods:
  - Bailing (with driller's bailer)
  - Intermittent pumping (rapid pump on/off cycles)
  - Surging (with surge block {piston})
  - Jetting (high pressure water streams)
  - Others- surfactants, dry ice, etc.

Test Pumping

- Purposes:
  - determine well performance
  - help in pump selection
- Procedures:
  - Pump at constant rate for period of time; measure Q and drawdown
  - Step tests (different flow rates)
    - Start at 10% of est. max. yield; measure Q & drawdown
    - Increase flow rate; repeat Q & drawdown measurements

Well Yield vs. Drawdown



Irrigation Water Quality

- Sediment: suspended sand, silt and clay
- Total salinity: dissolved mineral salts
- Sodicity: sodium content of dissolved minerals
- Toxic minerals: boron, chlorides, etc.

Sediment

- Sediment: suspended sand, silt and clay
- Effects:
  - emitter clogging
  - nozzle wear and clogging
  - capacity of canals, reservoirs, pipelines reduced
- Control:
  - large particles- sediment basins, cyclonic separators
  - small particles- filters, flocculation/filtration