



Groundwater Wells
Source Water Protection

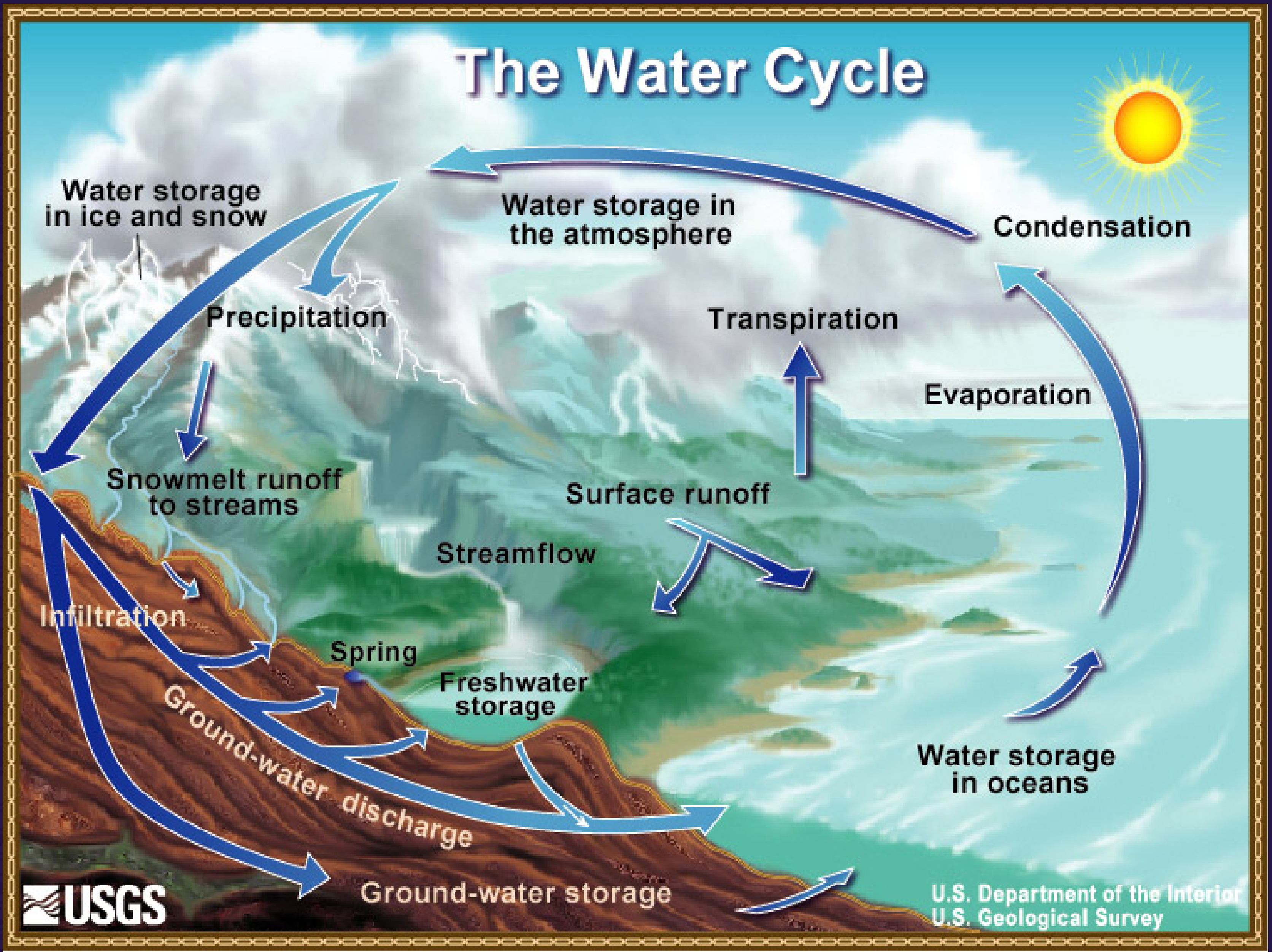
Daniel B. Stephens & Associates, Inc.

Where is the world's water?

- Saline water in oceans: 97.2%
- Ice caps and glaciers: 2.14%
- Groundwater: 0.61%
- Surface water: 0.009%
- Soil moisture: 0.005%
- Atmosphere: 0.001%

if world's water is represented by 1 gallon, than all the groundwater + surface water would not even be 5 teaspoons (4.68 teaspoons)

Source: Fetter, 1994

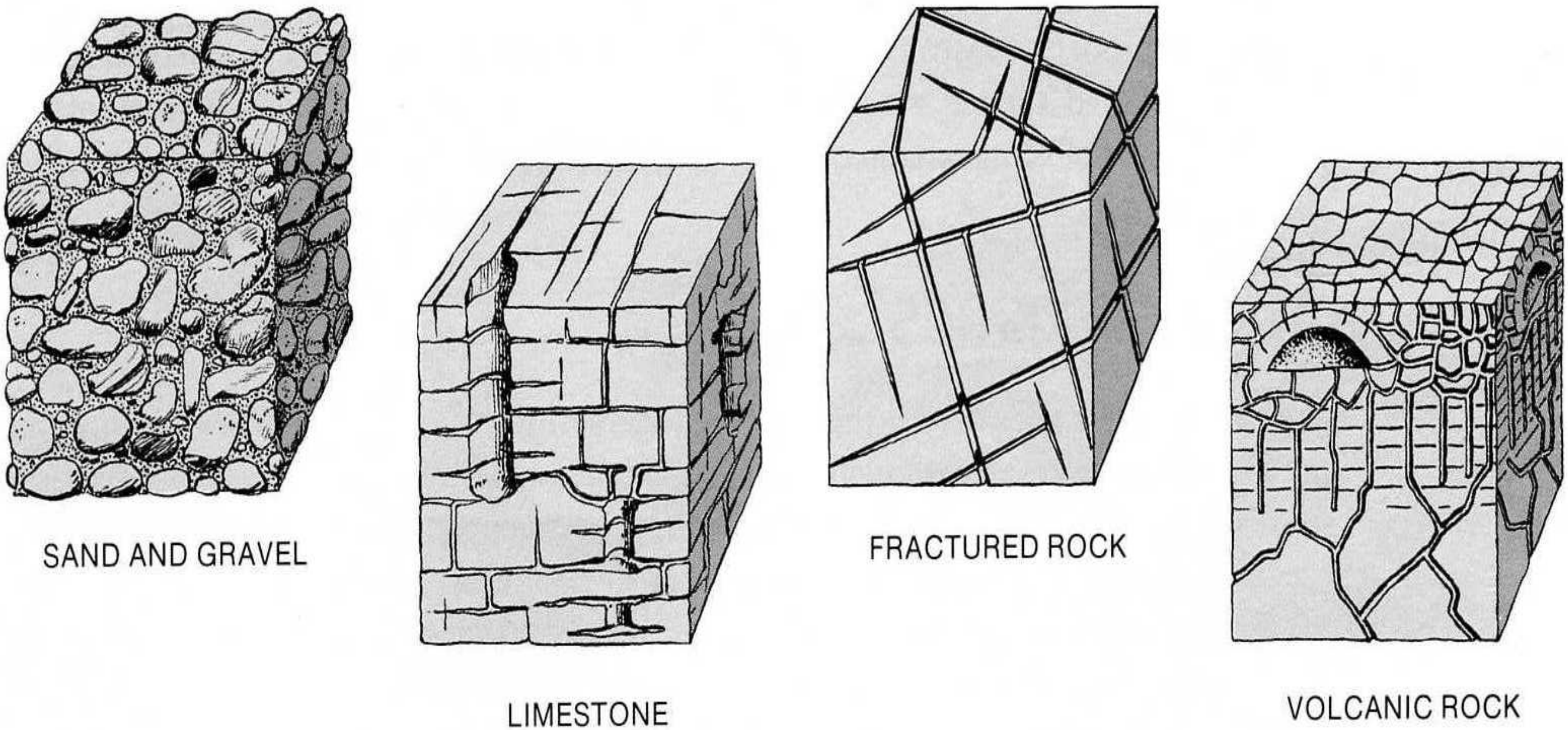

The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Precipitation
Transpiration
Evaporation
Snowmelt runoff to streams
Surface runoff
Streamflow
Infiltration
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS
U.S. Department of the Interior
U.S. Geological Survey

What is an aquifer?

- "A geologic formation with sufficient interconnected porosity and permeability to store and transmit significant quantities of water under natural hydraulic gradients"

Source: Cleary, R.W. 2003. *The groundwater pollution and hydrology course.*

Four Common Rock Types

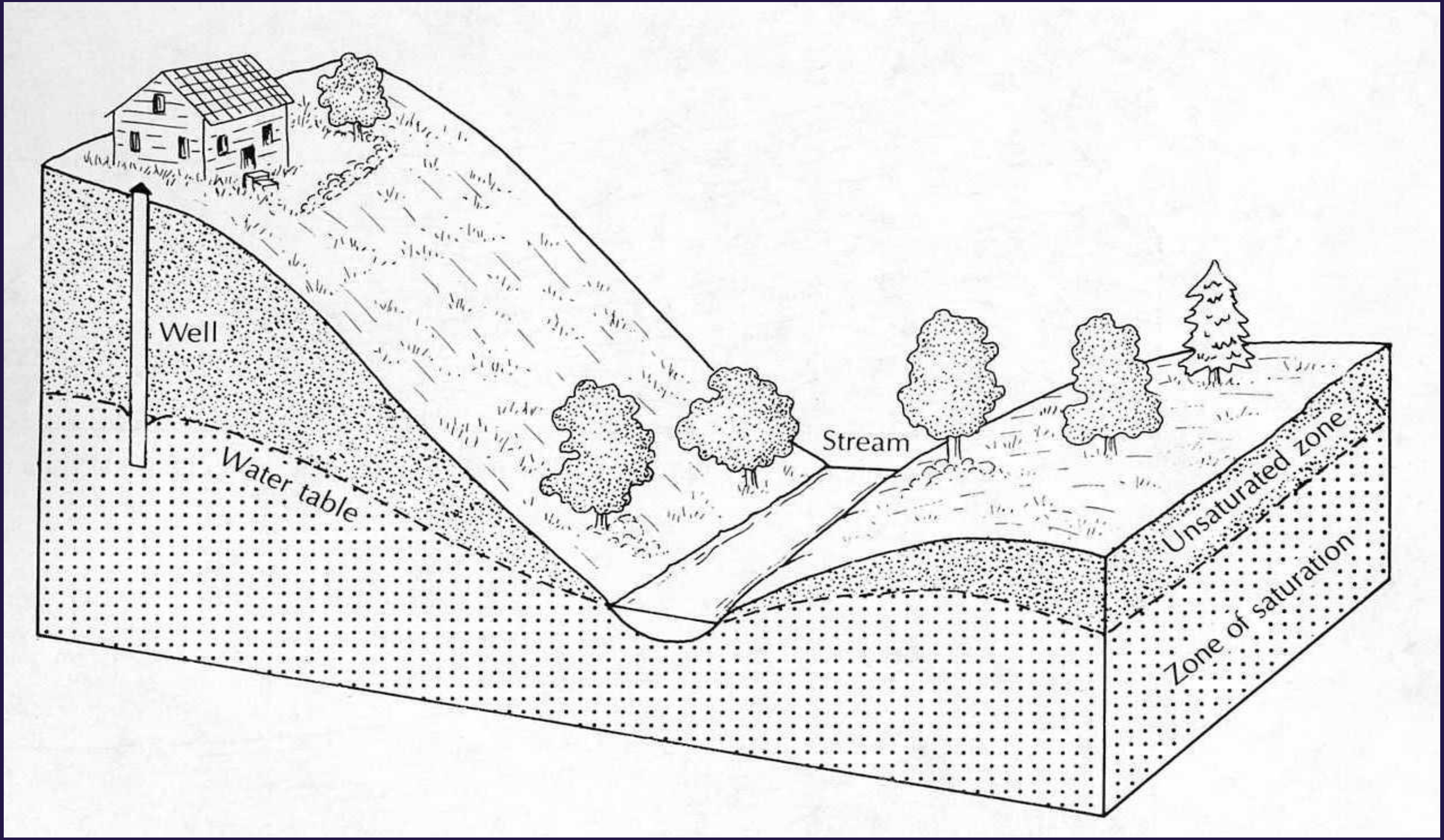


Source: AWWA well performance series – pt 1, 1986

Aquifer Types

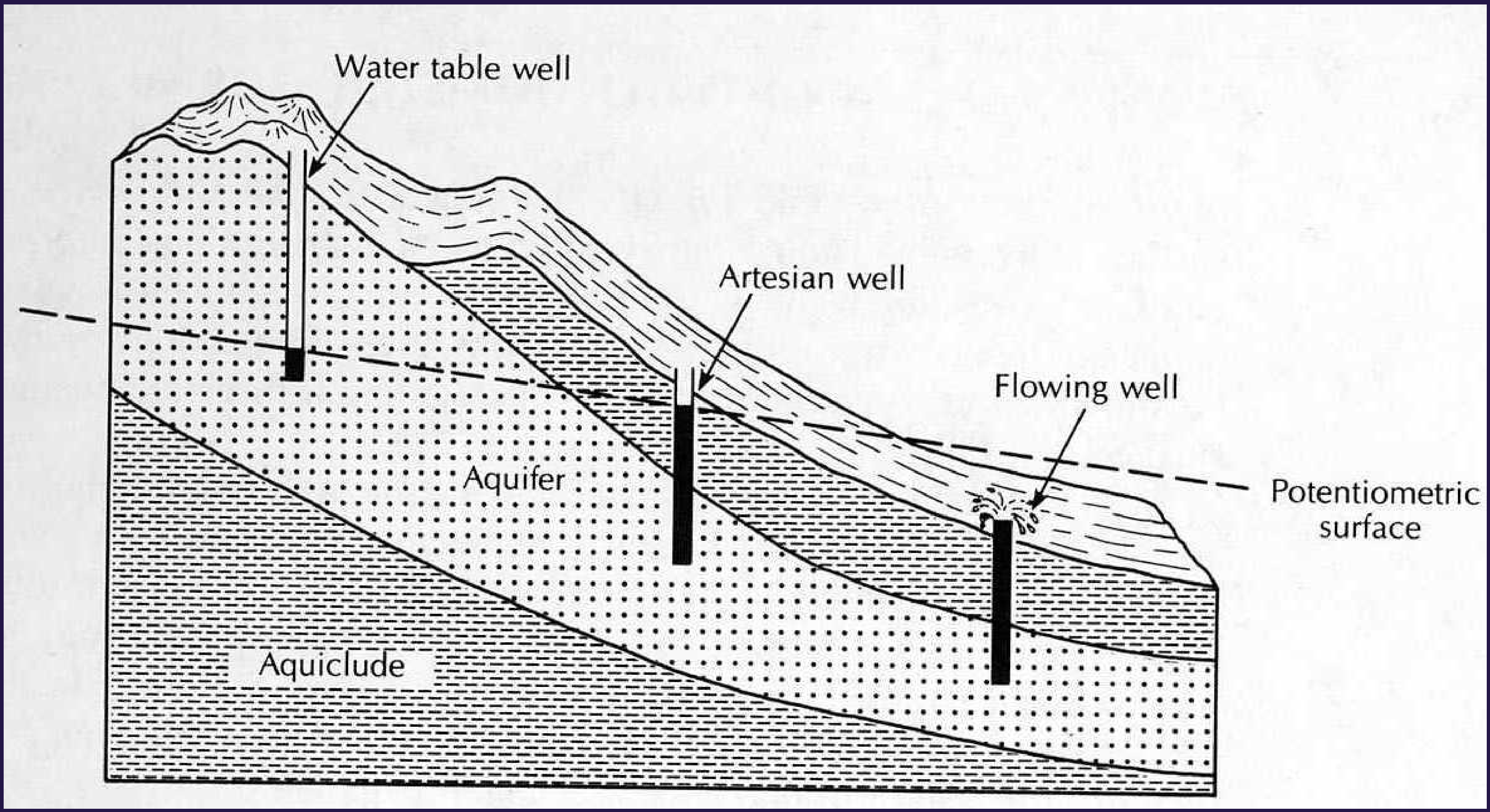
- Unconfined (water table)
- Confined
- Perched

Unconfined Aquifer



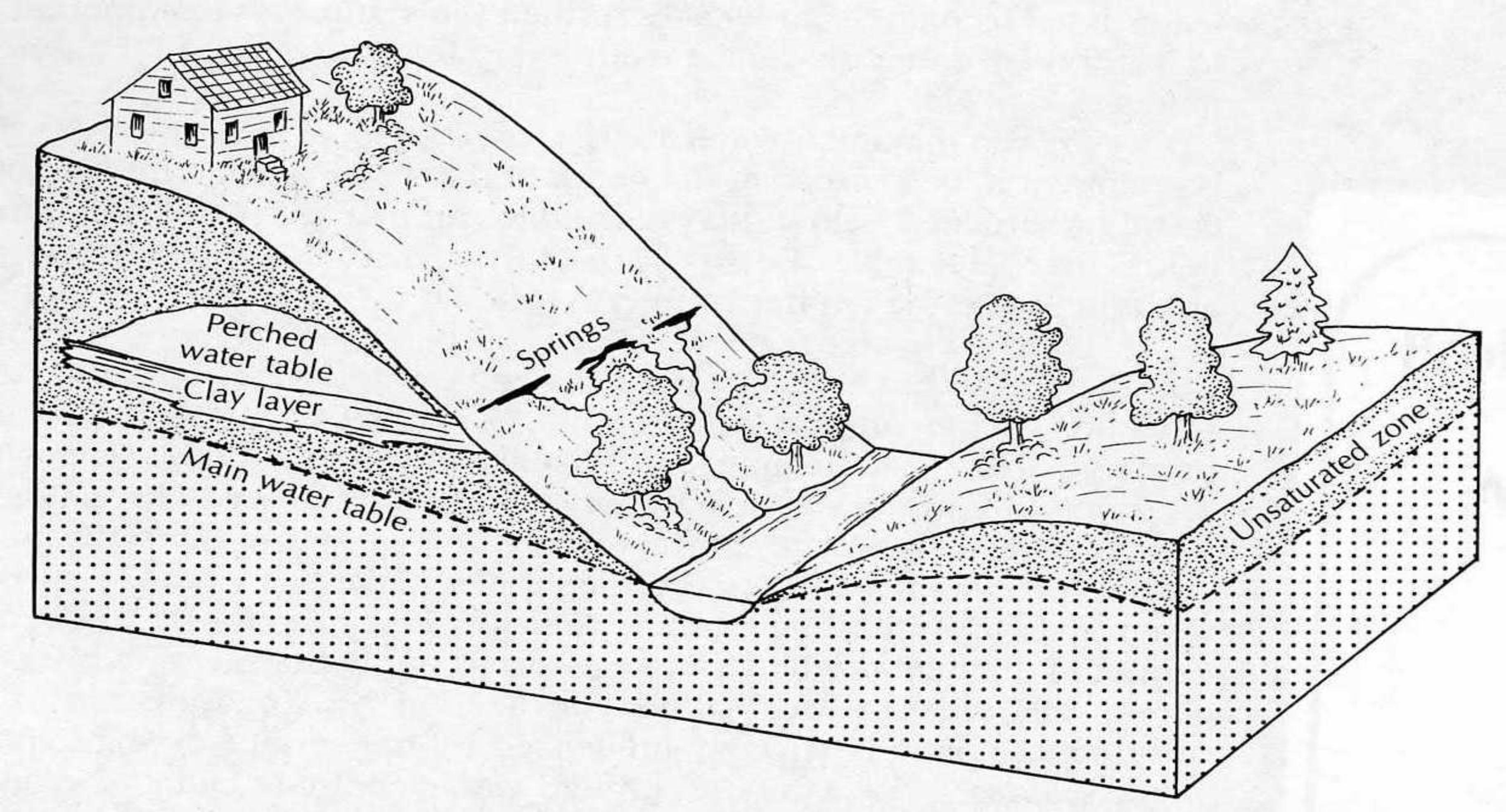
Source: Fetter, 1994

Confined Aquifer



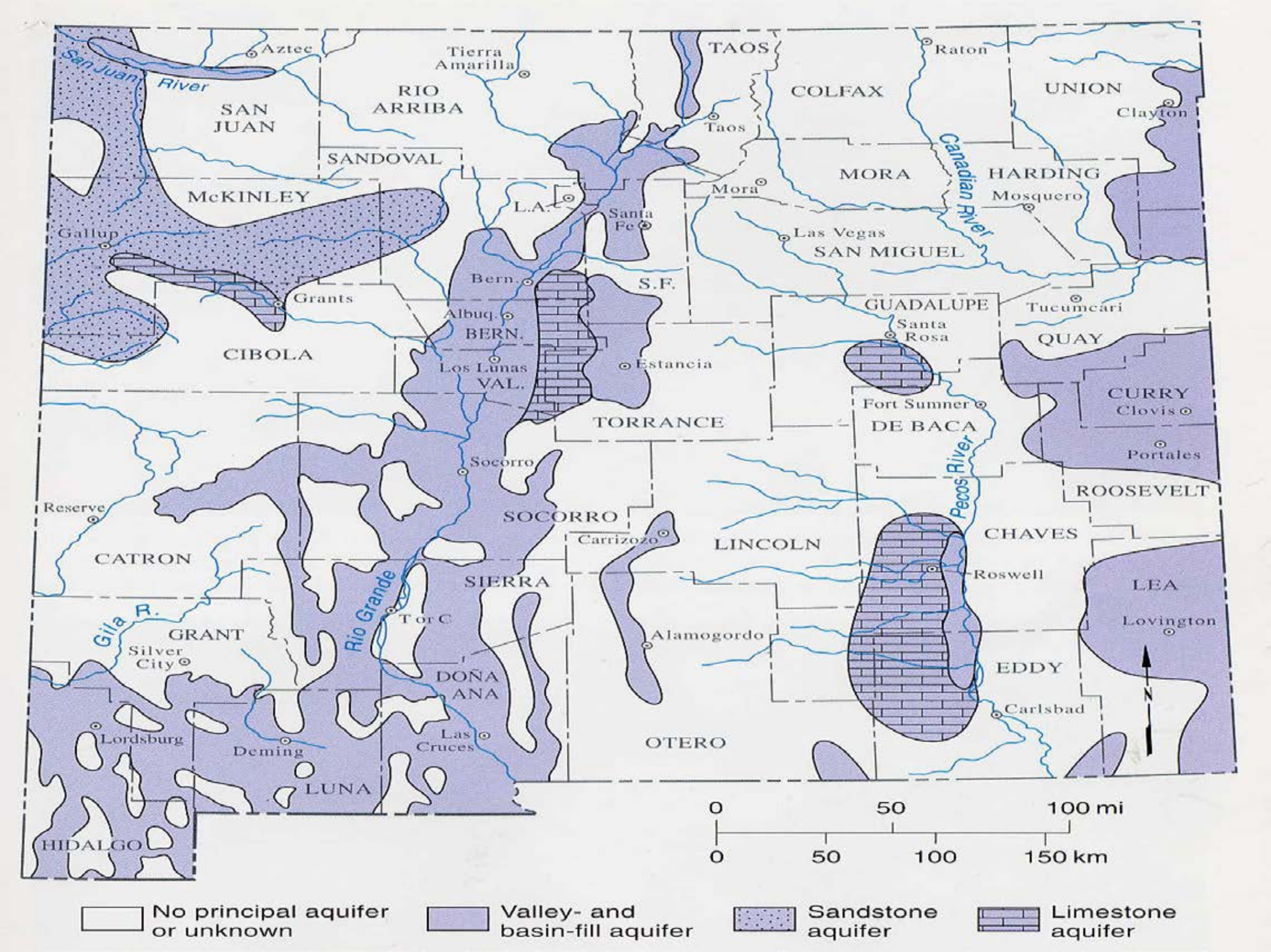
Source: Fetter, 1994

Perched Aquifer



Source: Fetter, 1994

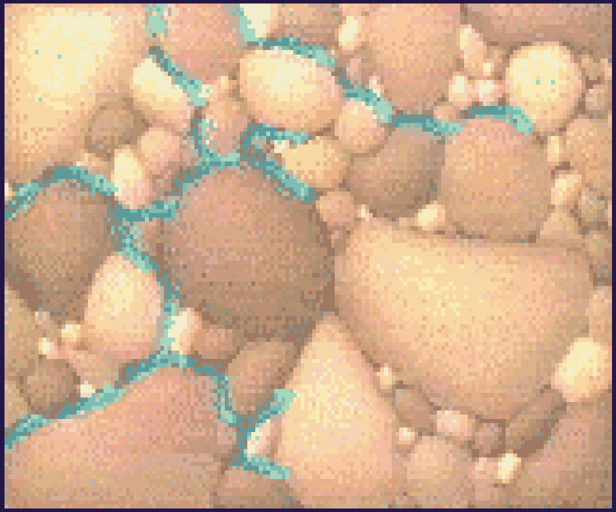
General New Mexico Aquifers

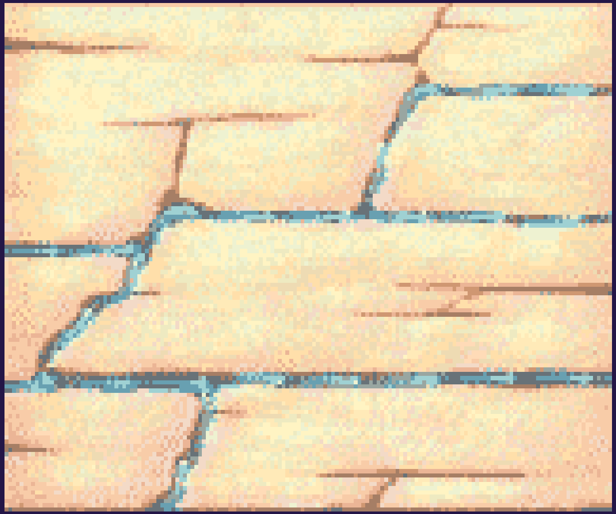


Source: Our water resources, 2001

Groundwater Movement

- Movement from areas of high head to areas of low head (hydraulic gradient)
  - Head = pressure, elevation, kinetic energy
  - Hydraulic conductivity: capacity to transmit water
  - Transmissivity: volumetric flow rate ($m^3/d/m$)
  - Porosity = void volume
  - Permeability (connectivity, ease of movement)
  - Specific Yield: % of void volume that





Porosity Values

Unconsolidated Sediments	η (%)	Consolidated Rocks	η (%)
Clay	45–55	Sandstone	5–30
Silt	35–50	Limestone/dolomite (original & secondary porosity	1–20
Sand	25–40	Shale	0–10
Gravel	25–40	Fractured crystalline rock	0–10
Sand & gravel mixes	10–35	Vesicular basalt	10–50
Glacial till	10–25	Dense, solid rock	< 1

Specific Yield Values

Unconsolidated Sediments	η (%)	Consolidated Rocks	η (%)
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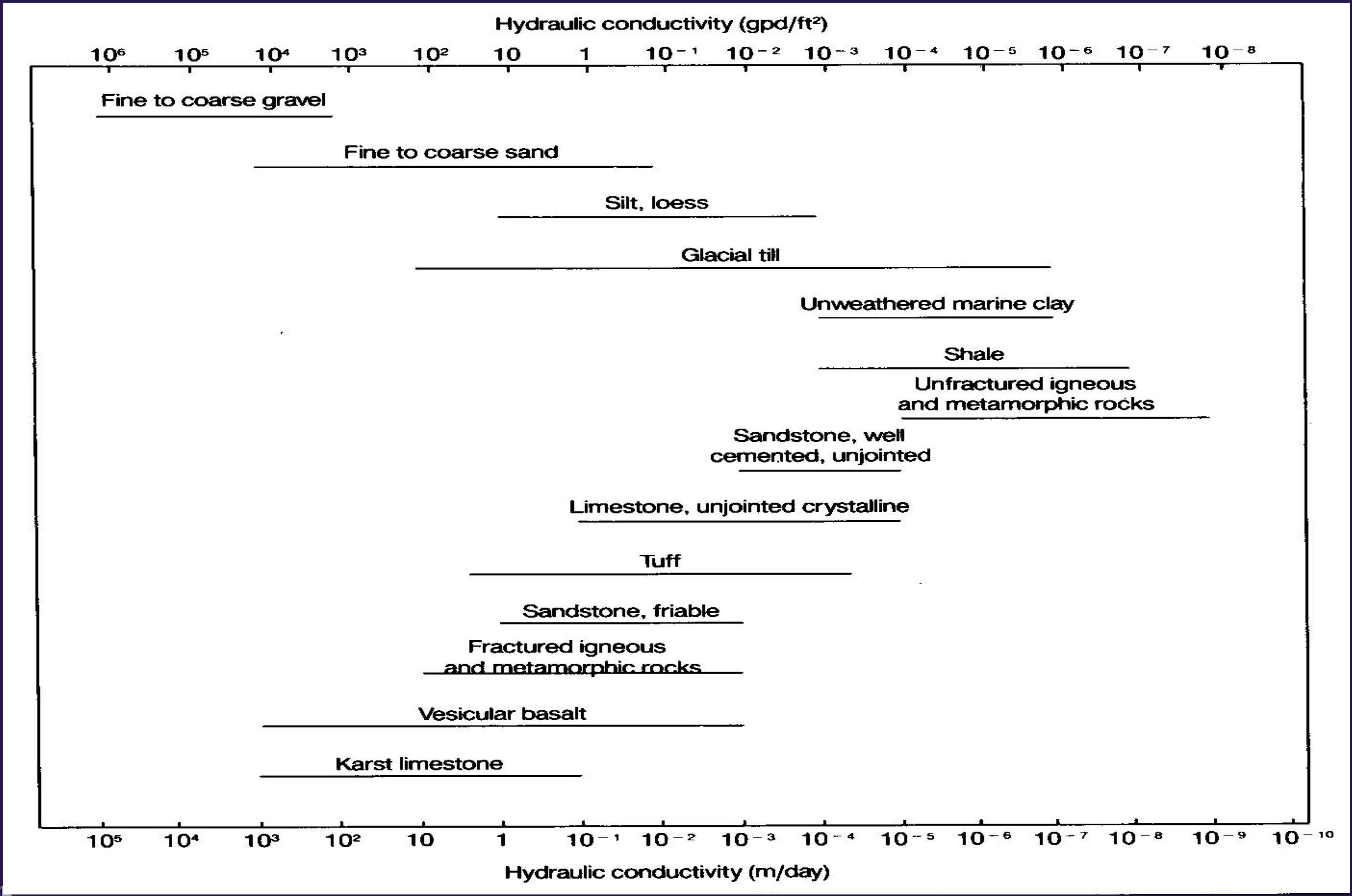
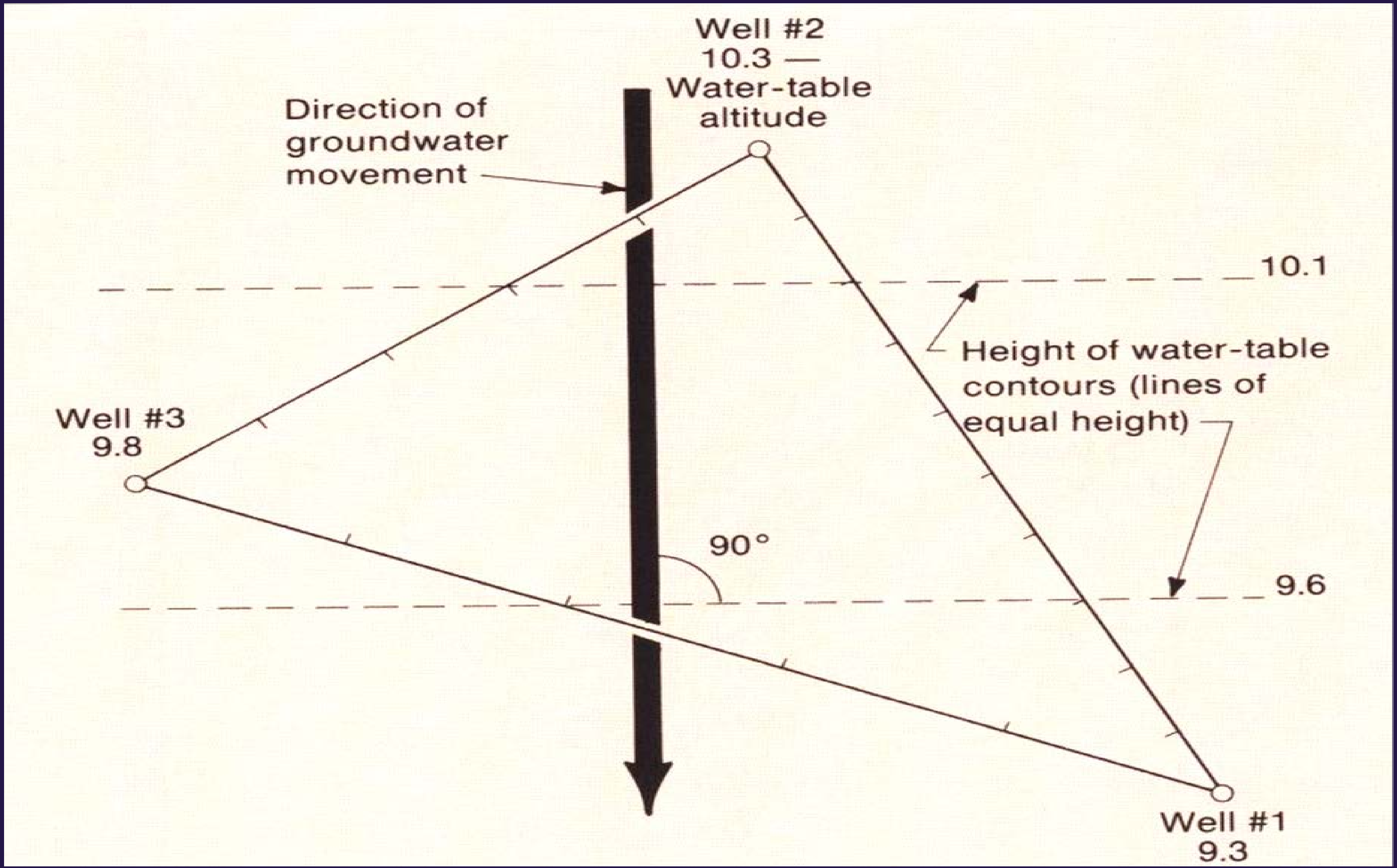
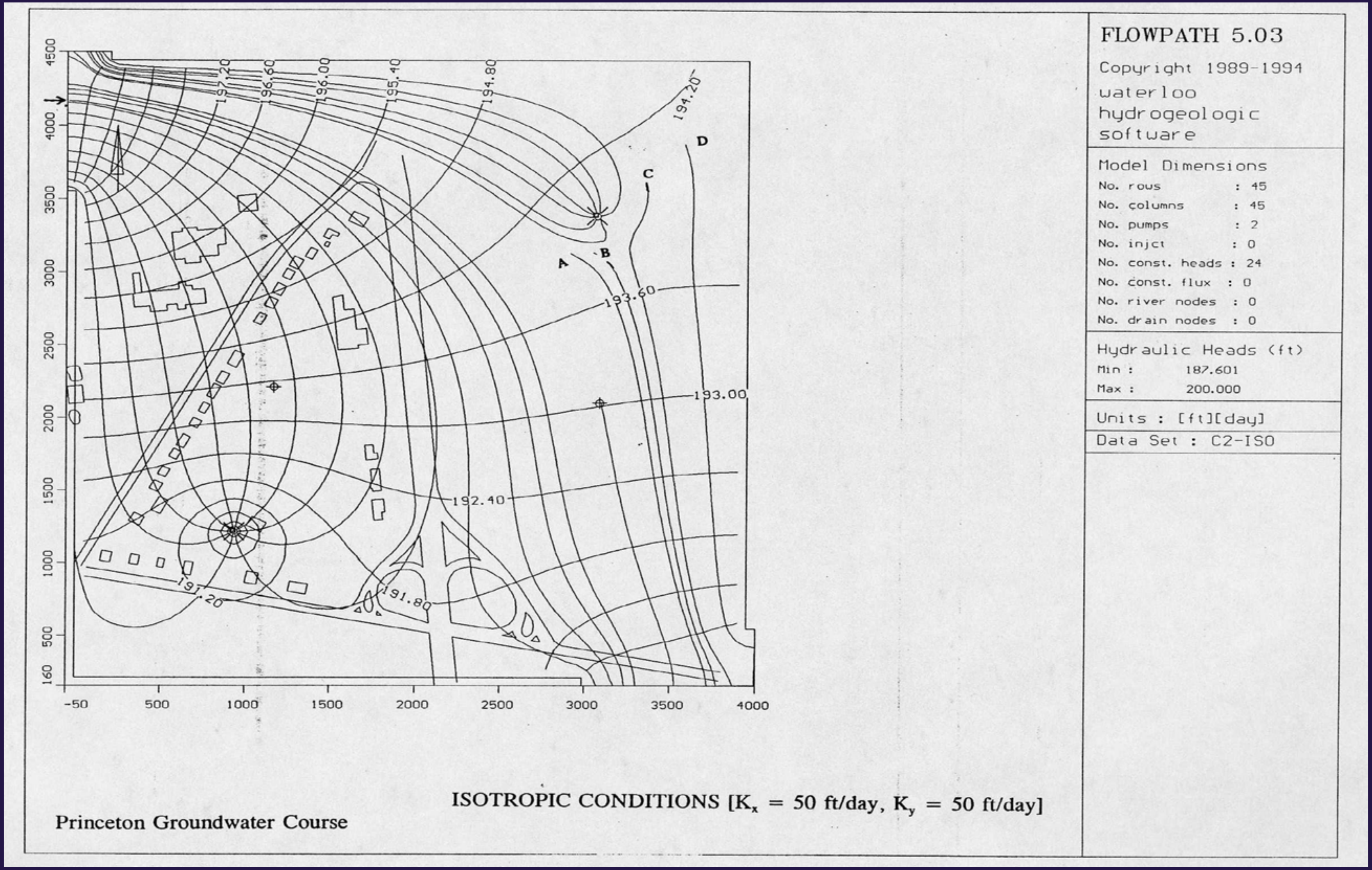
Hydraulic Conductivity Values



Determining Aquifer Flow

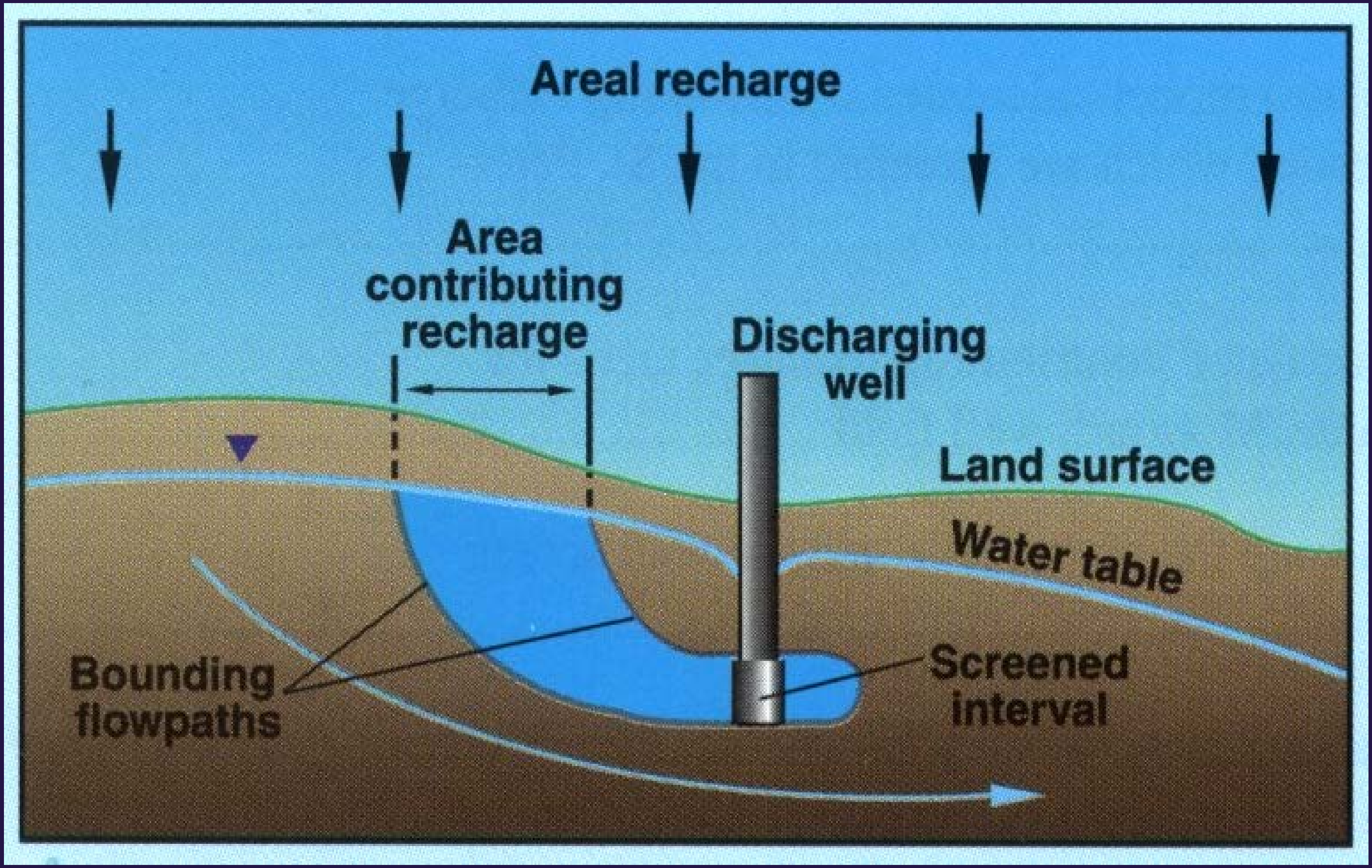


Groundwater Movement (cont.)



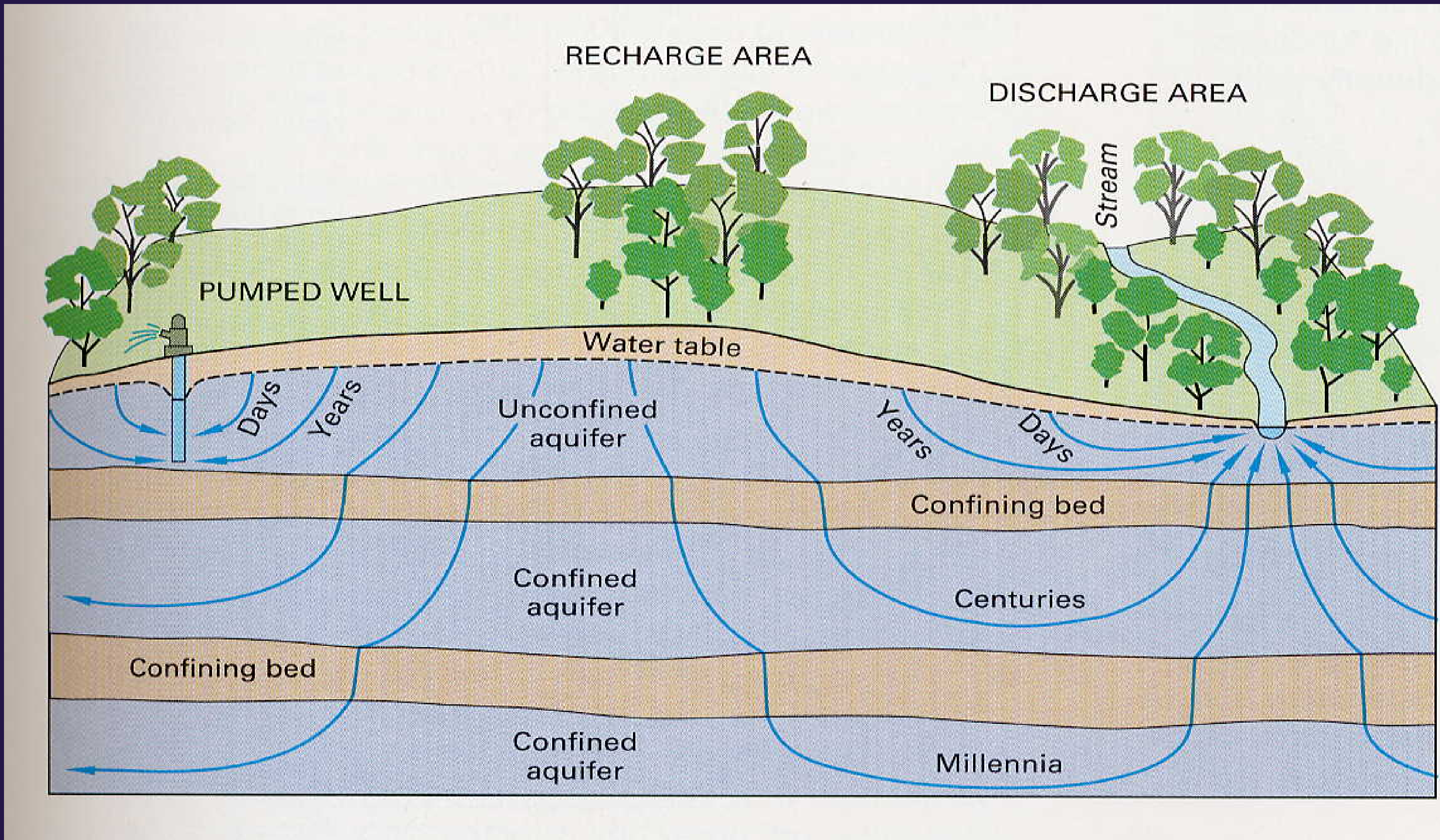
Source: Cleary, 2003

Groundwater Recharge and Discharge



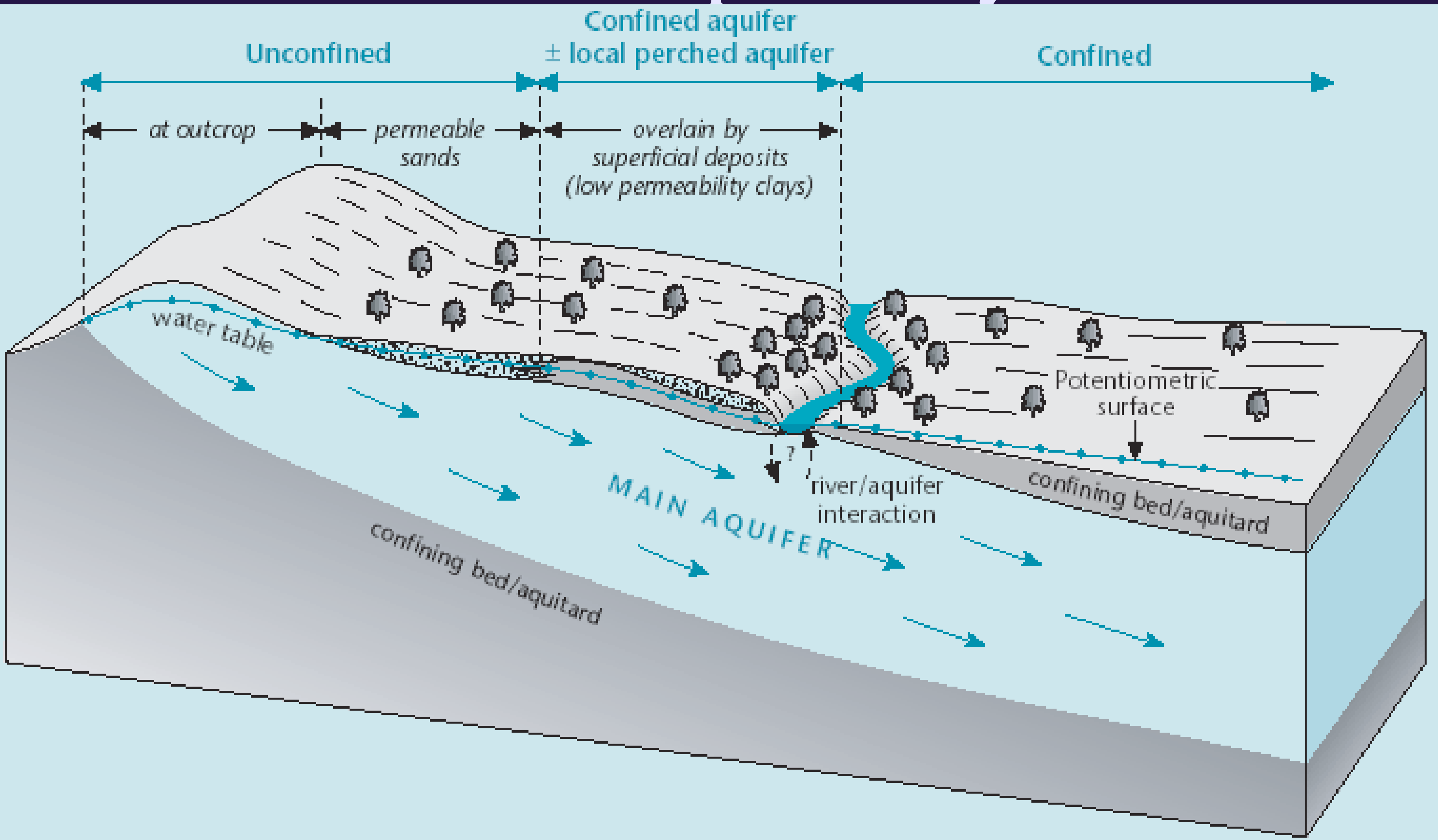
Source: USGS Circular 1174

Recharge and Discharge (cont.)

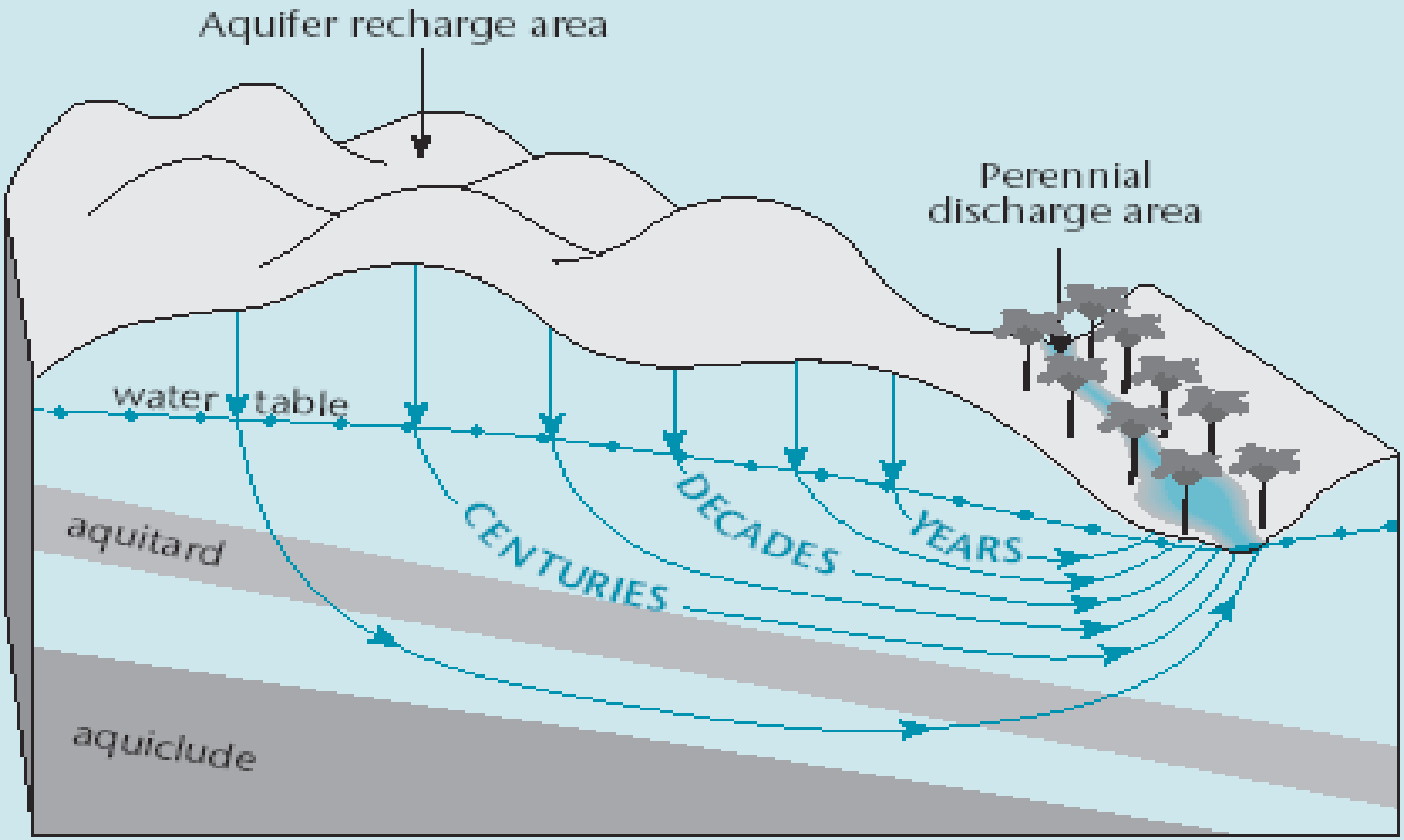


Source: USGS Circular 1139

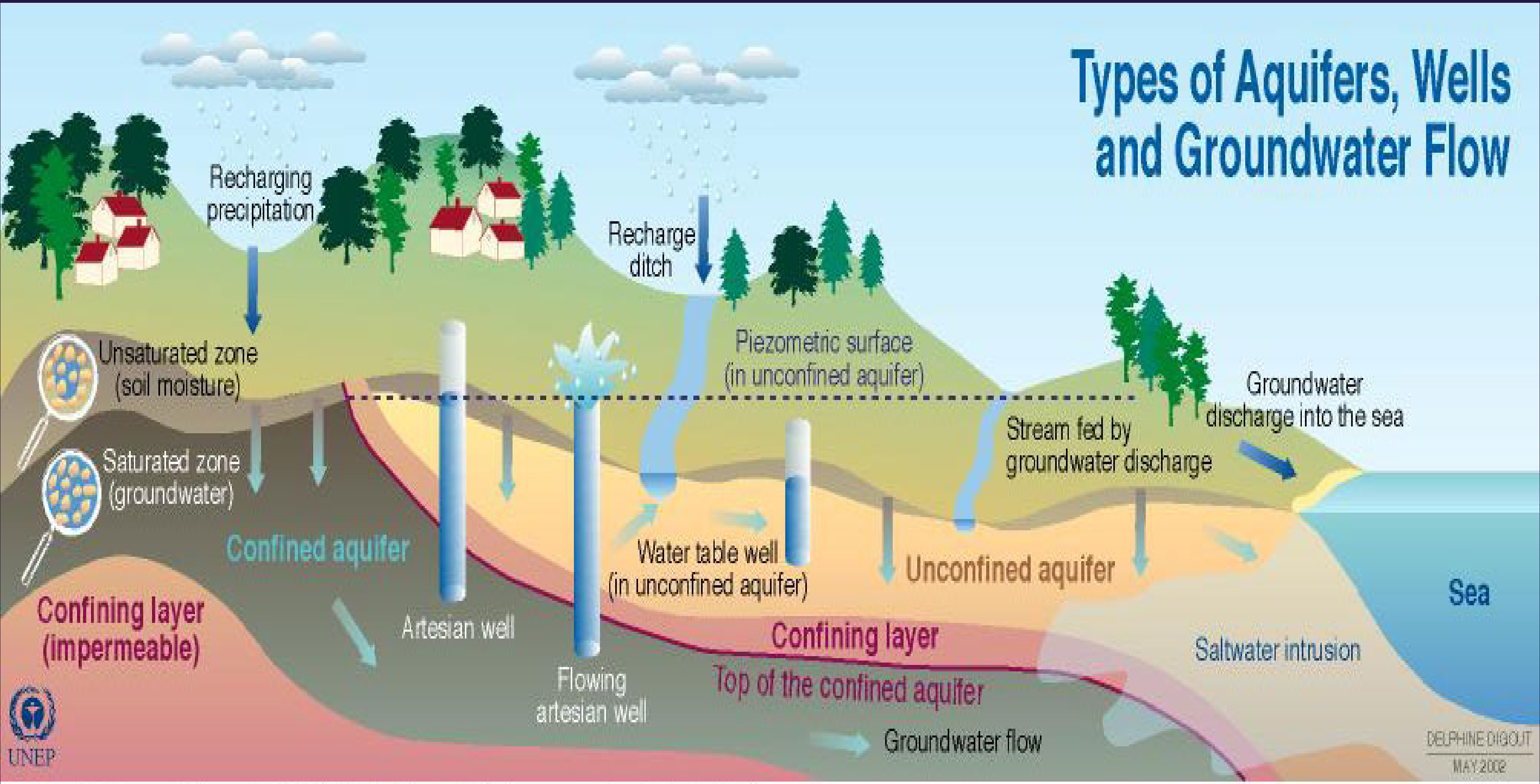
Common Aquifer System



Regional Aquifer Flow System



The Groundwater System



Source: Environment Canada, 2001 (Adapted from: http://www.ec.ca/water/index.htm).

Water Wells 101

When it was drilled in the early 1990s, this was the largest water well in the world. There is tremendous artesian pressure at this location. When this well came in, it blew out rocks the size of basketballs 20 feet into the air! (Edwards Aquifer, Southern Bexar County, TX)

Well Drilling & Development

Well Drilling

Cable Tool or Percussion Method

- Impact created by raising and dropping a heavy drill bit
- Cuttings are extracted with a bailer

Rotary Drilled/Reverse Rotary Drilled

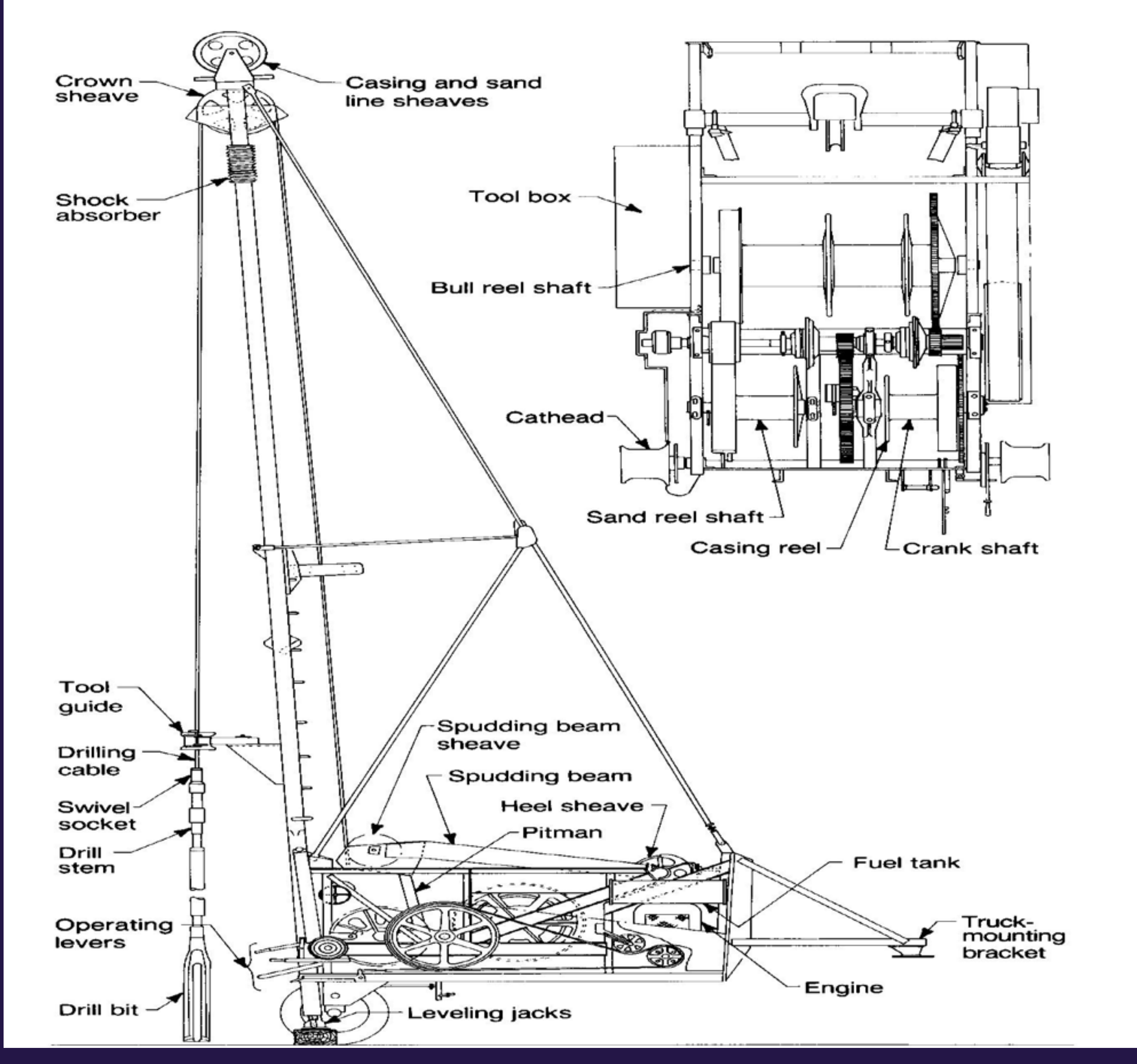
- Power driven drill stems cut formation
- Drilling mud is pumped down to cool the bit
- Cuttings are brought to the surface via the casing or drill stem

Air Rotary

- Impact created by pneumatic air hammer
- Cuttings are brought up to surface by air pressure

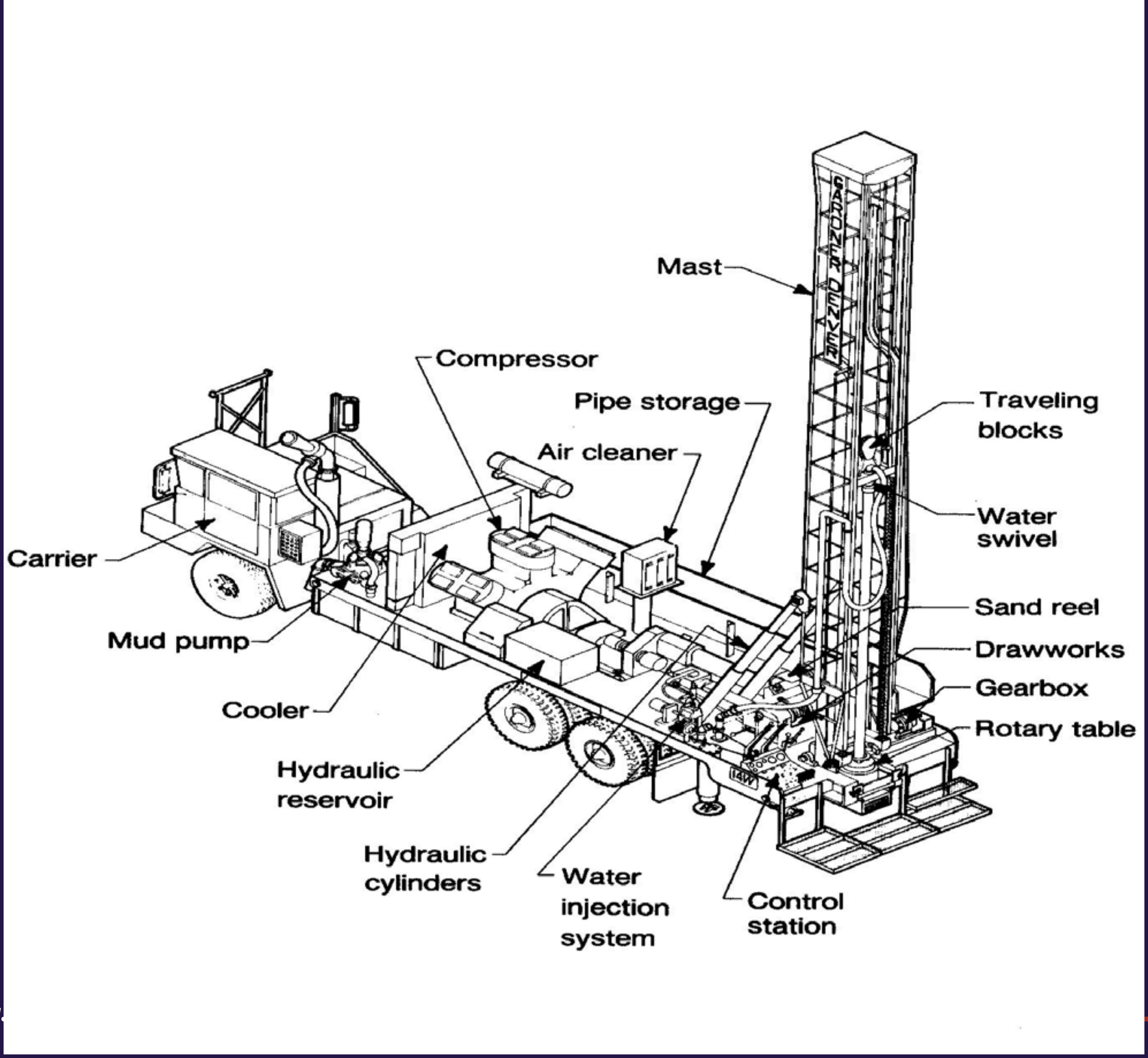
Well Drilling

Cable Tool Method



Well Drilling

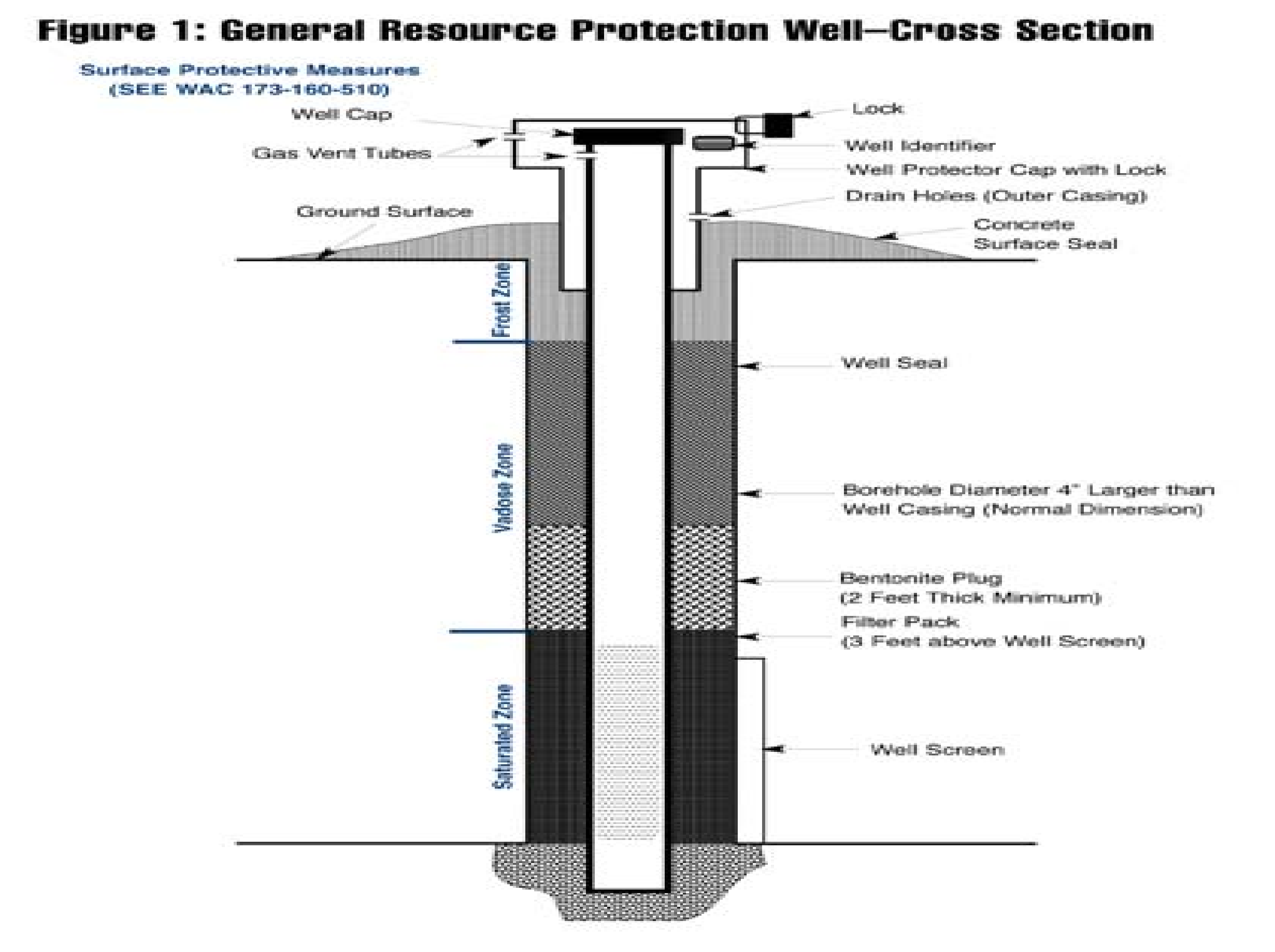
Rotary Method



Well Drilling

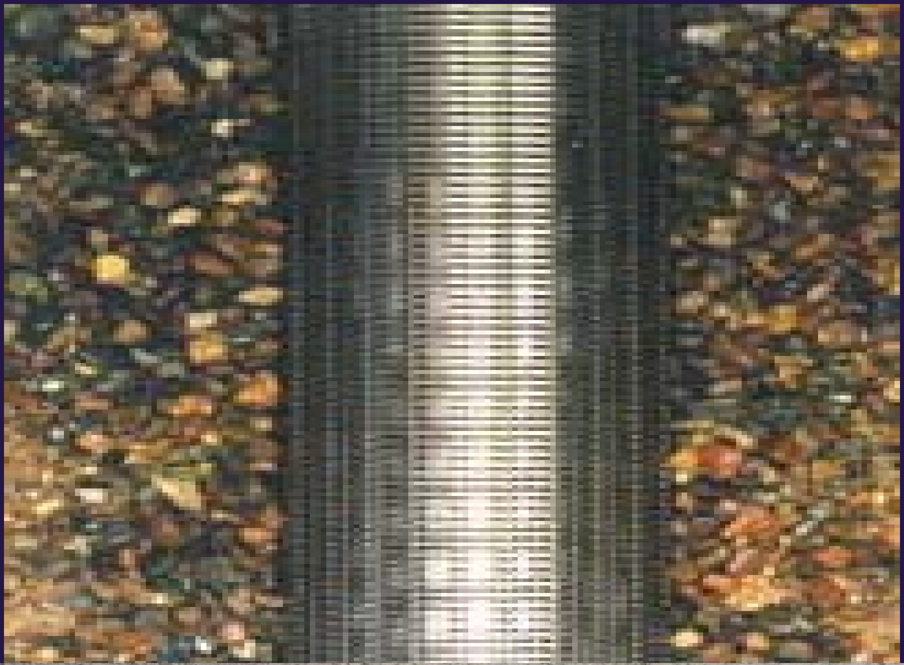
Air Rotary Method

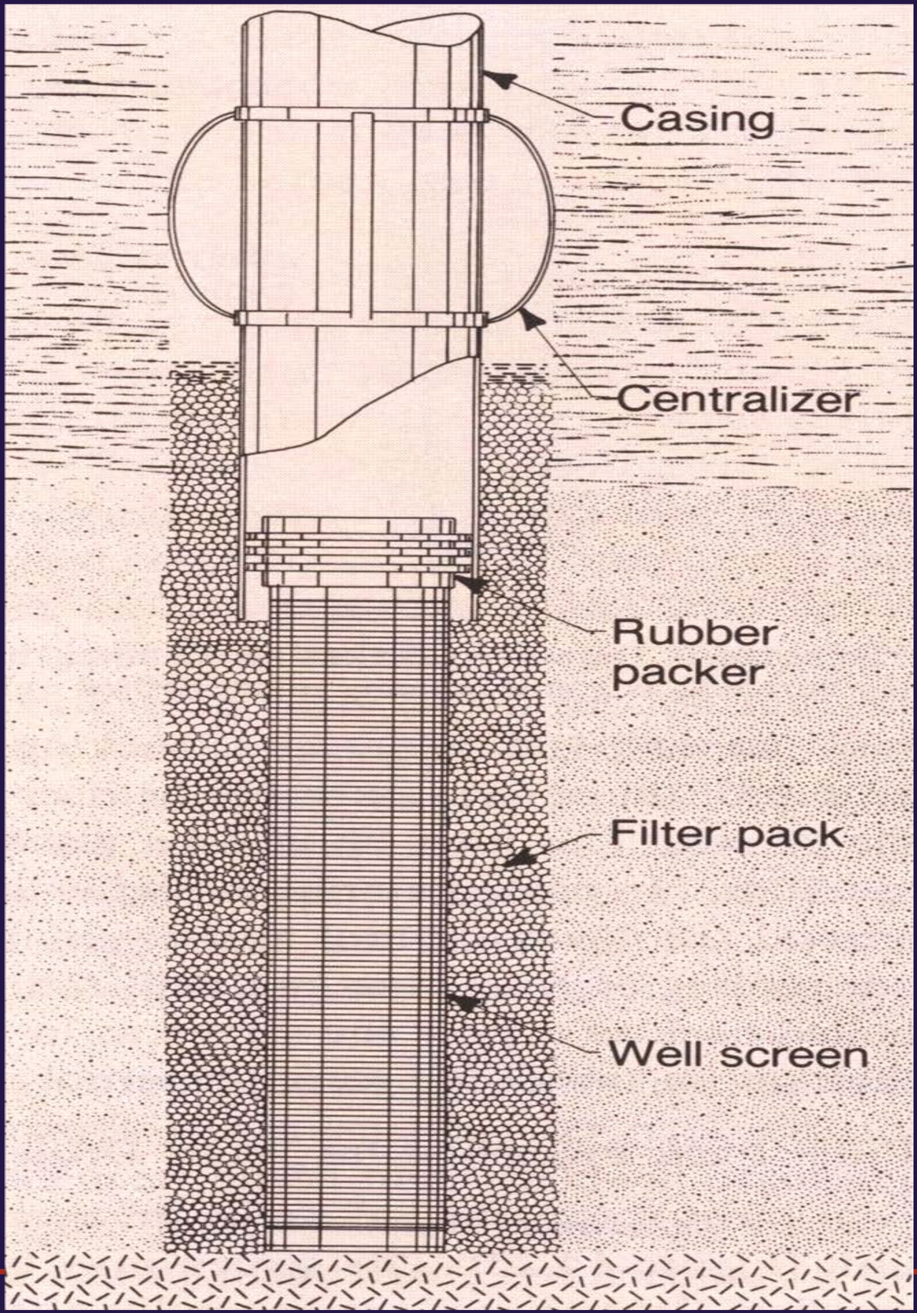
Well Development & Construction



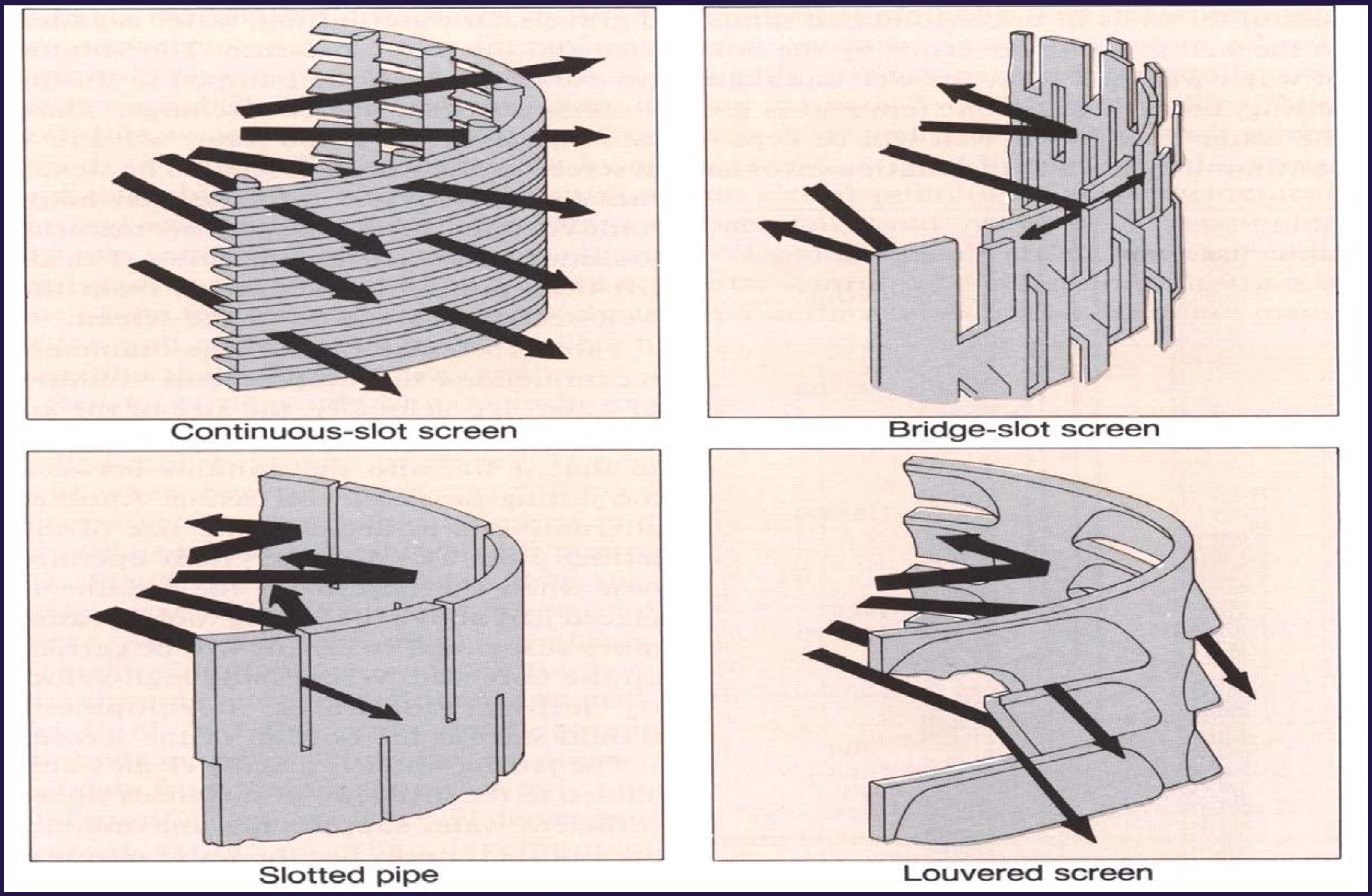
Source: http://www.nesc.wvu.edu/ndwc/articles/OT/FA03/TB_figure1.html

Gravel Pack & Screens





Screen Variety



Typical Water Well

Minimum well casing height from ground surface?

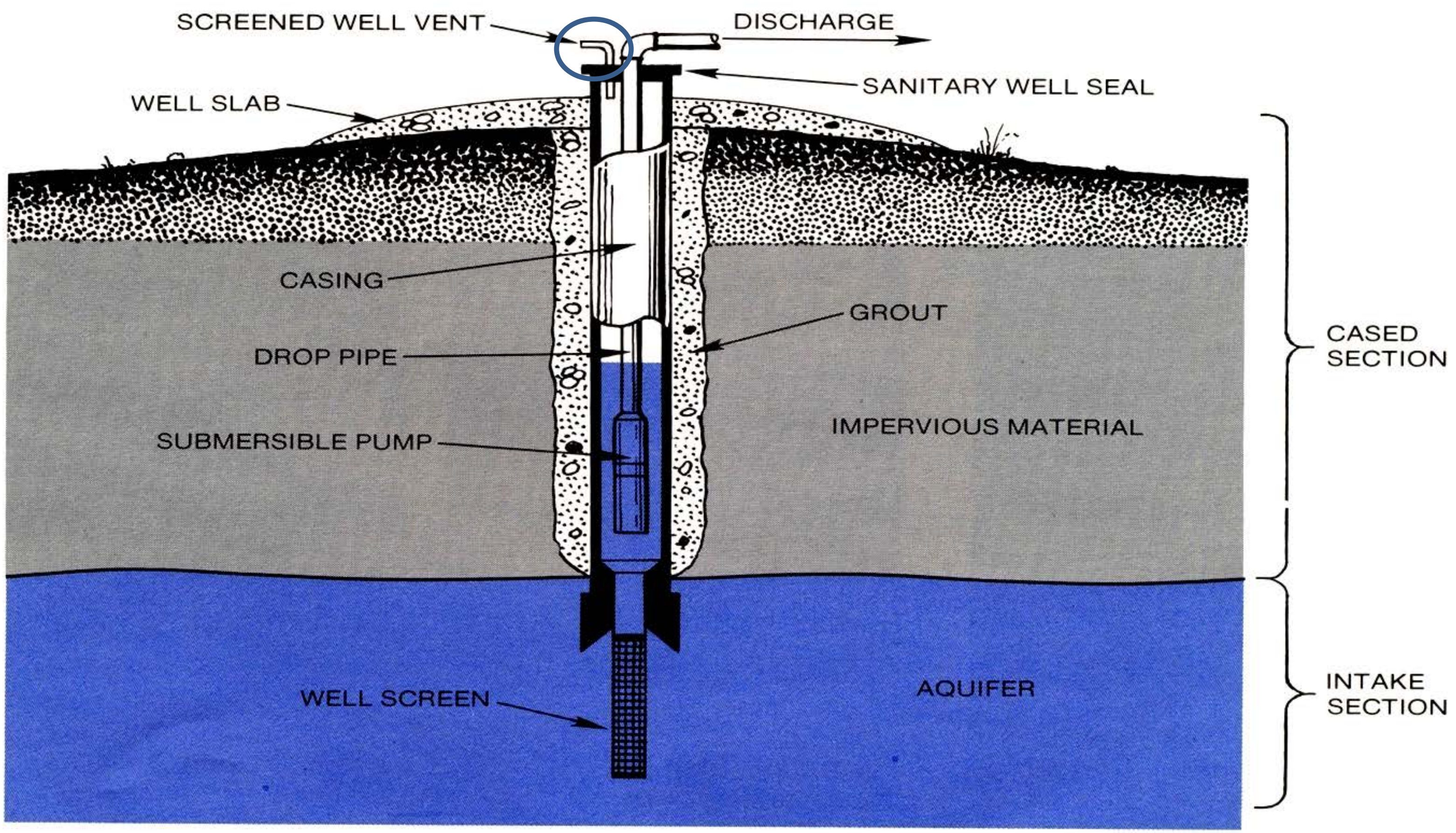


Figure 7 Major Sections of a Well

Source: AWWA well performance series – pt 1, 1986

Typical Water Well

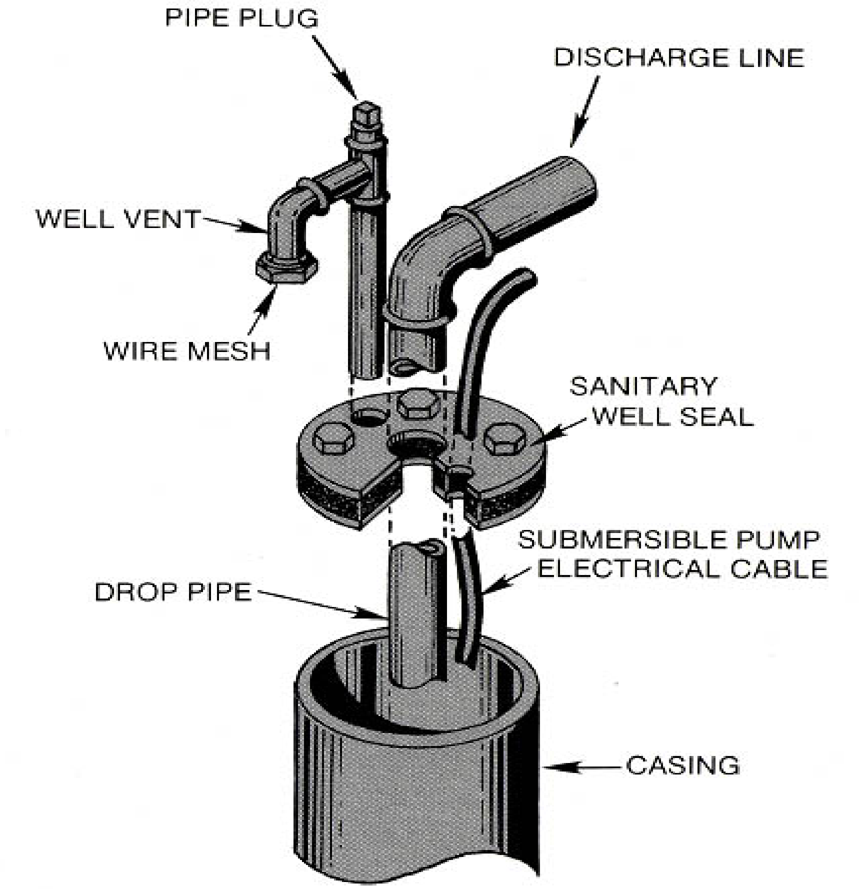
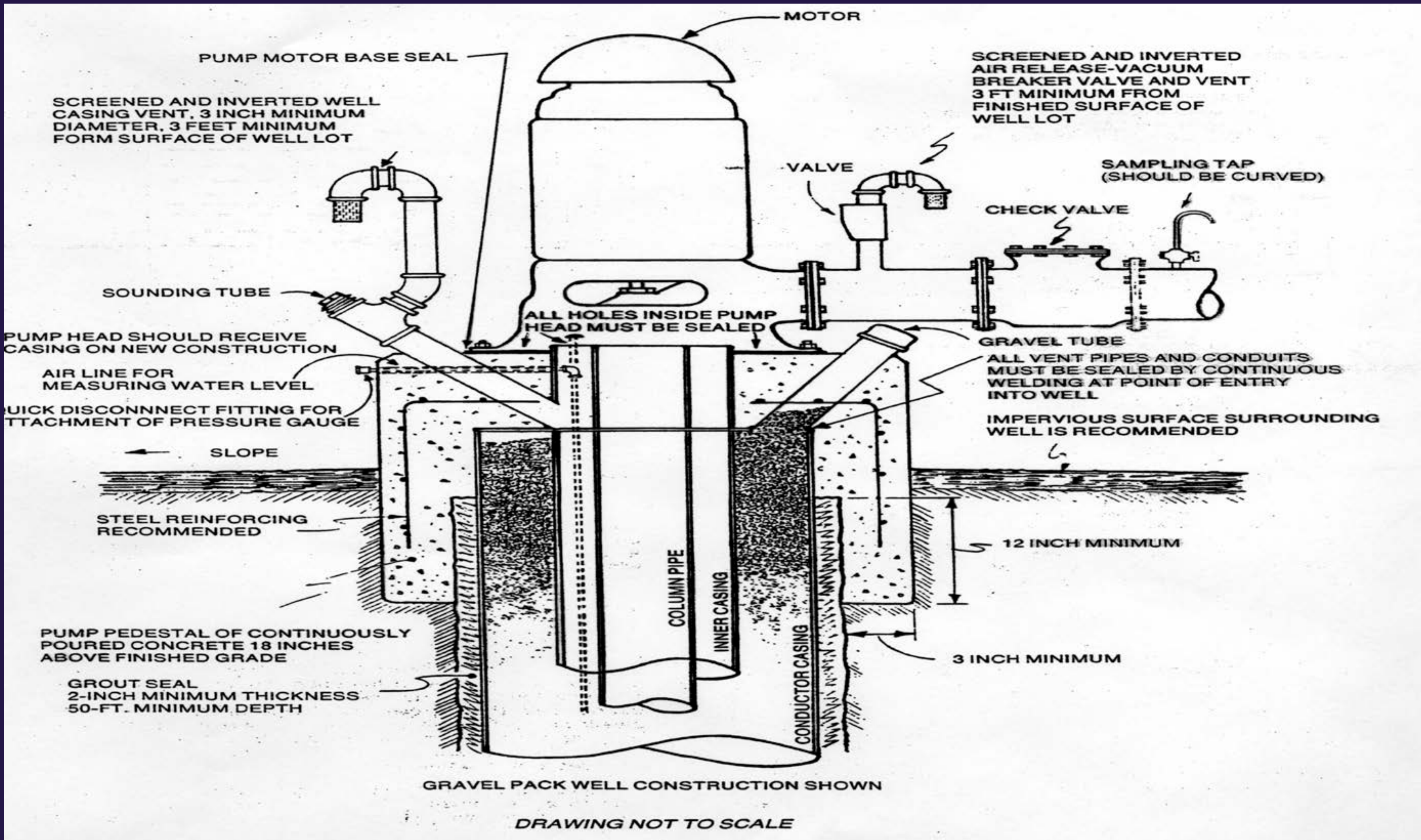


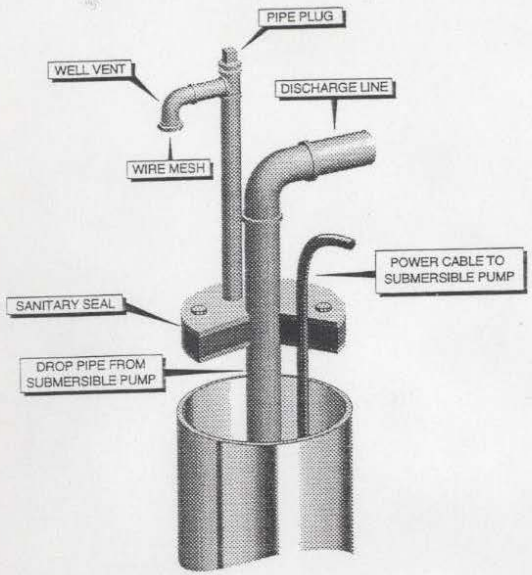
Figure 11 Sanitary Well Seal for Submersible Pump Installation

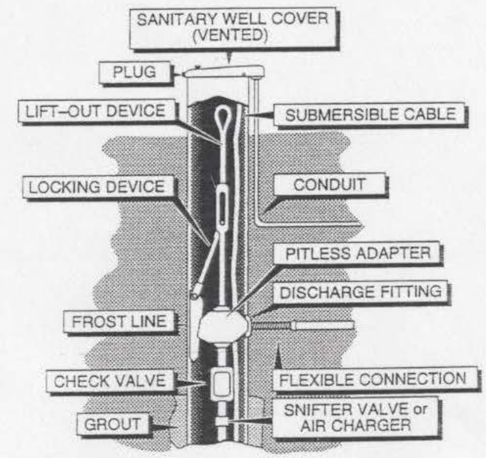
Source: AWWA well performance series – pt 1, 1986

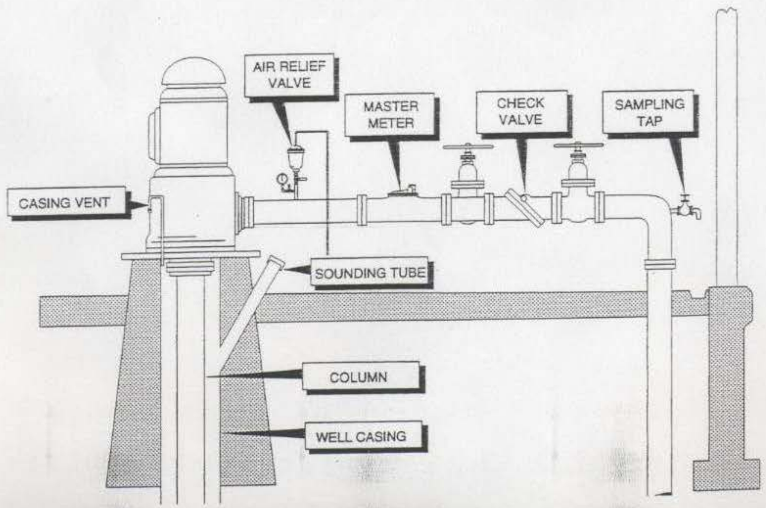
Typical Water Well



Source: AWWA well performance series – pt 1, 1986

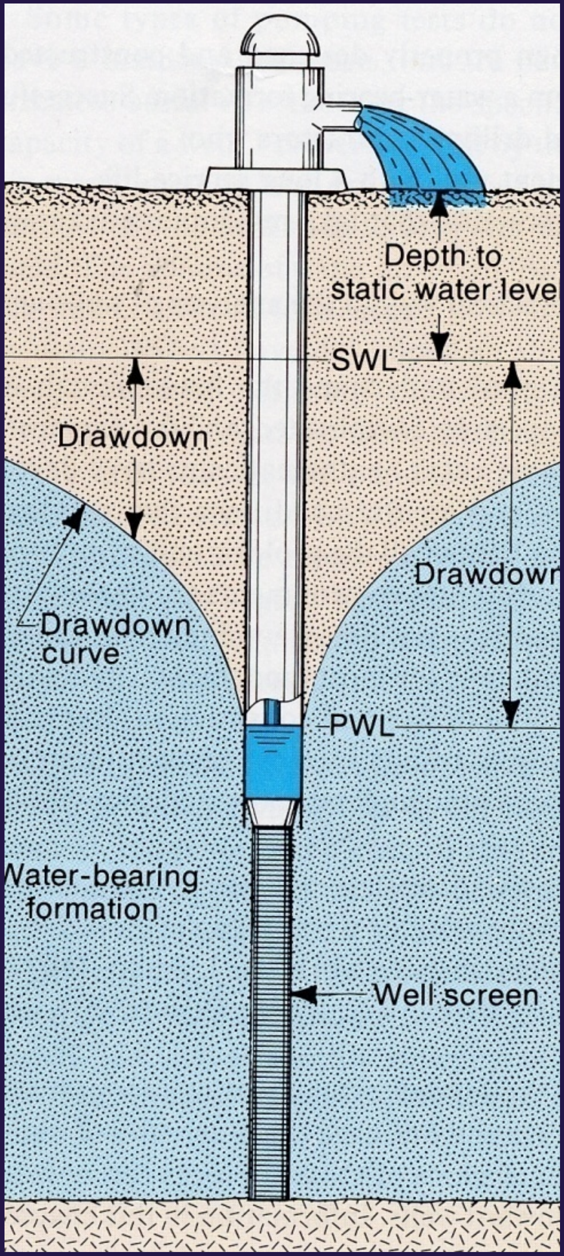

PIPE PLUG
WELL VENT
DISCHARGE LINE
WIRE MESH
POWER CABLE TO SUBMERSIBLE PUMP
SANITARY SEAL
DROP PIPE FROM SUBMERSIBLE PUMP


SANITARY WELL COVER (VENTED)
PLUG
LIFT-OUT DEVICE
SUBMERSIBLE CABLE
LOCKING DEVICE
CONDUIT
PITLESS ADAPTER
DISCHARGE FITTING
FROST LINE
CHECK VALVE
FLEXIBLE CONNECTION
GROUT
SNIFTER VALVE or AIR CHARGER


AIR RELIEF VALVE
MASTER METER
CHECK VALVE
SAMPLING TAP
CASING VENT
SOUNDING TUBE
COLUMN
WELL CASING

Well Hydraulics

- Static water level
- Pumping water level
- Drawdown
- Cone of depression
- Zone of capture (radius of influence)
- Equilibrium



Source: AWWA well performance series – pt 1, 1986

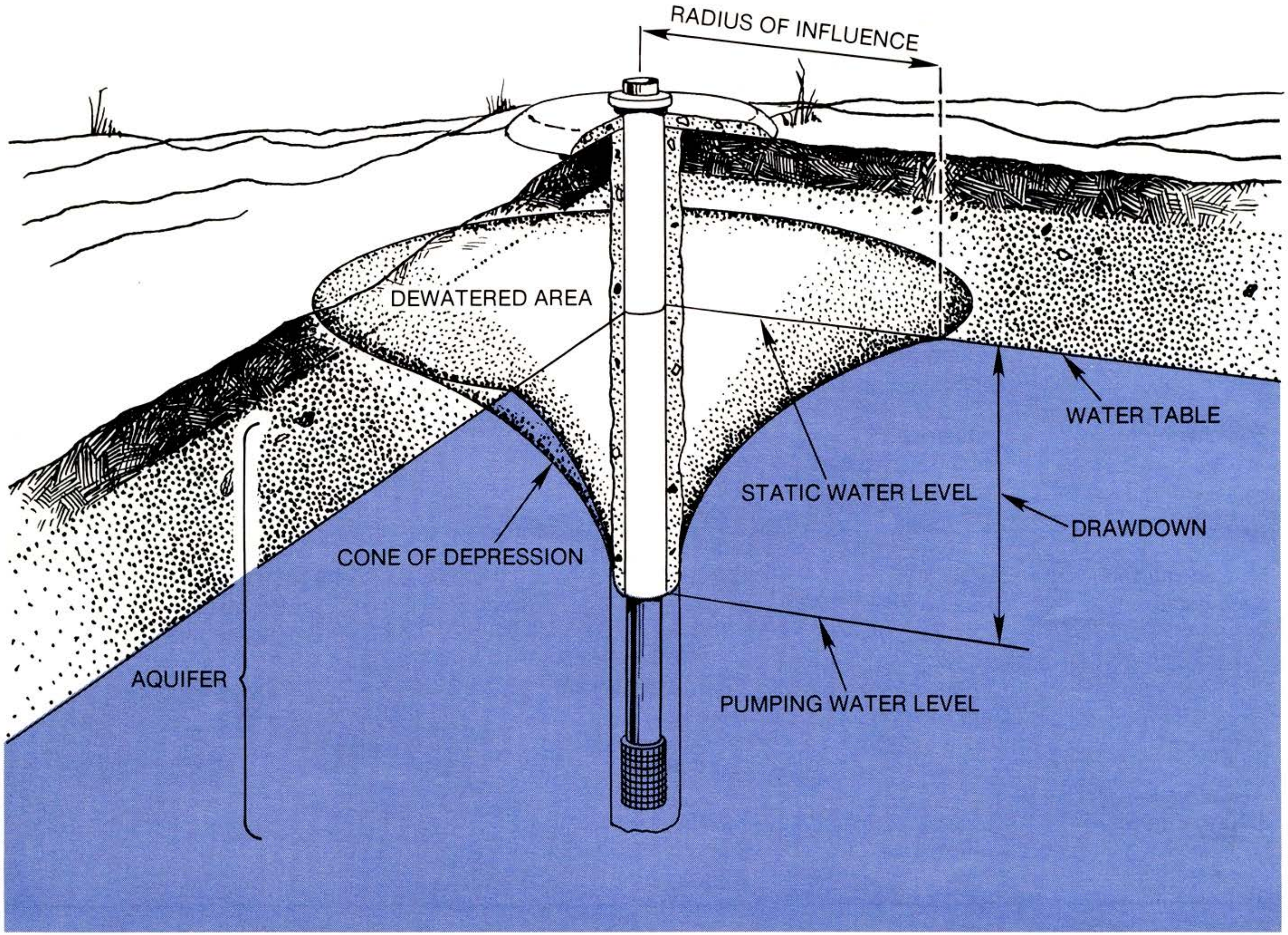
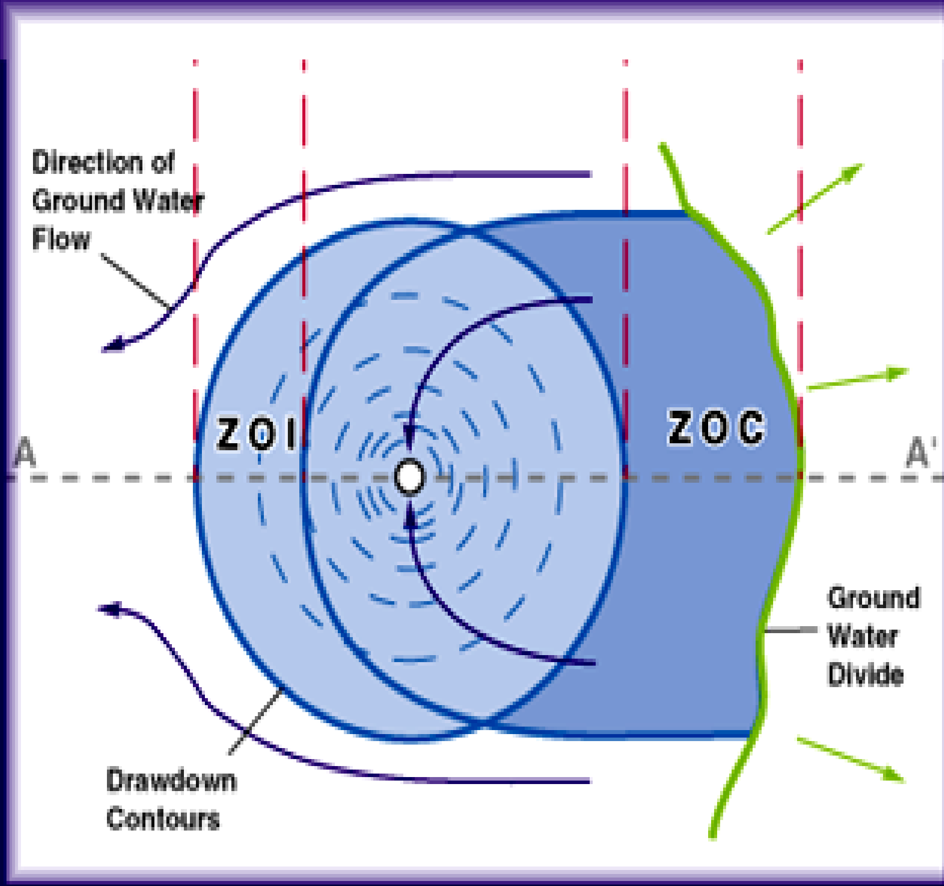


Figure 5 Common Water Well Terms and Measurements

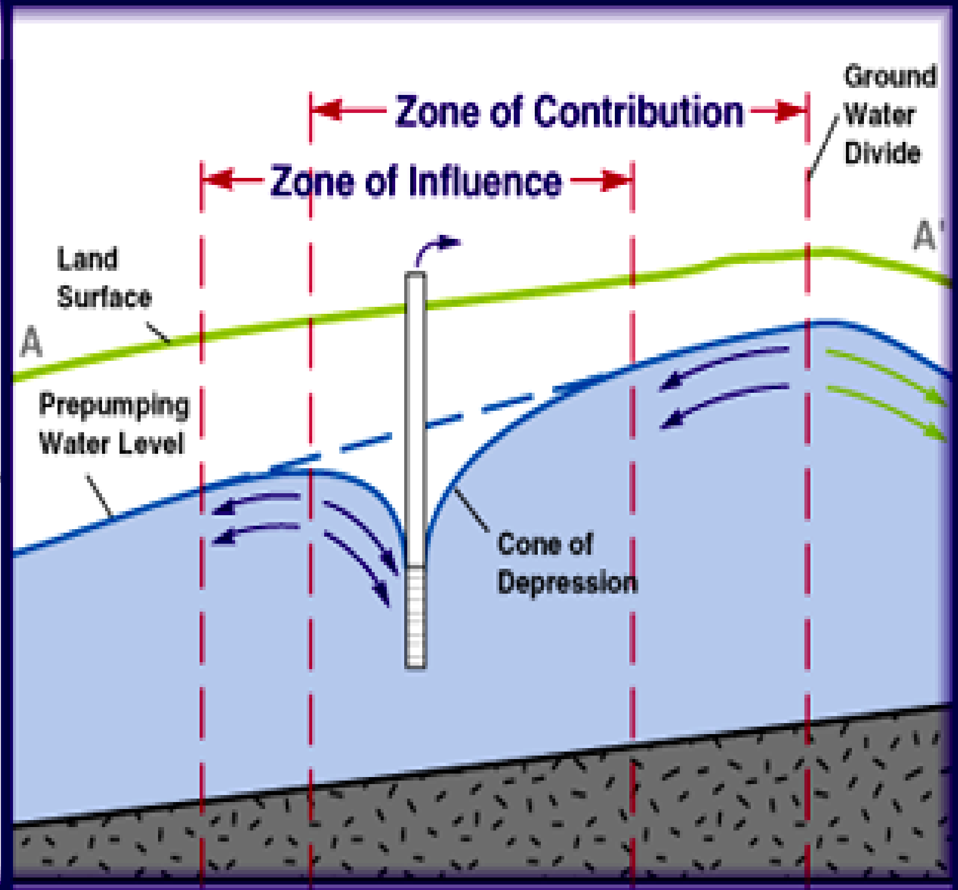
Source: AWWA well performance series – pt 1, 1986

Zone of Contribution

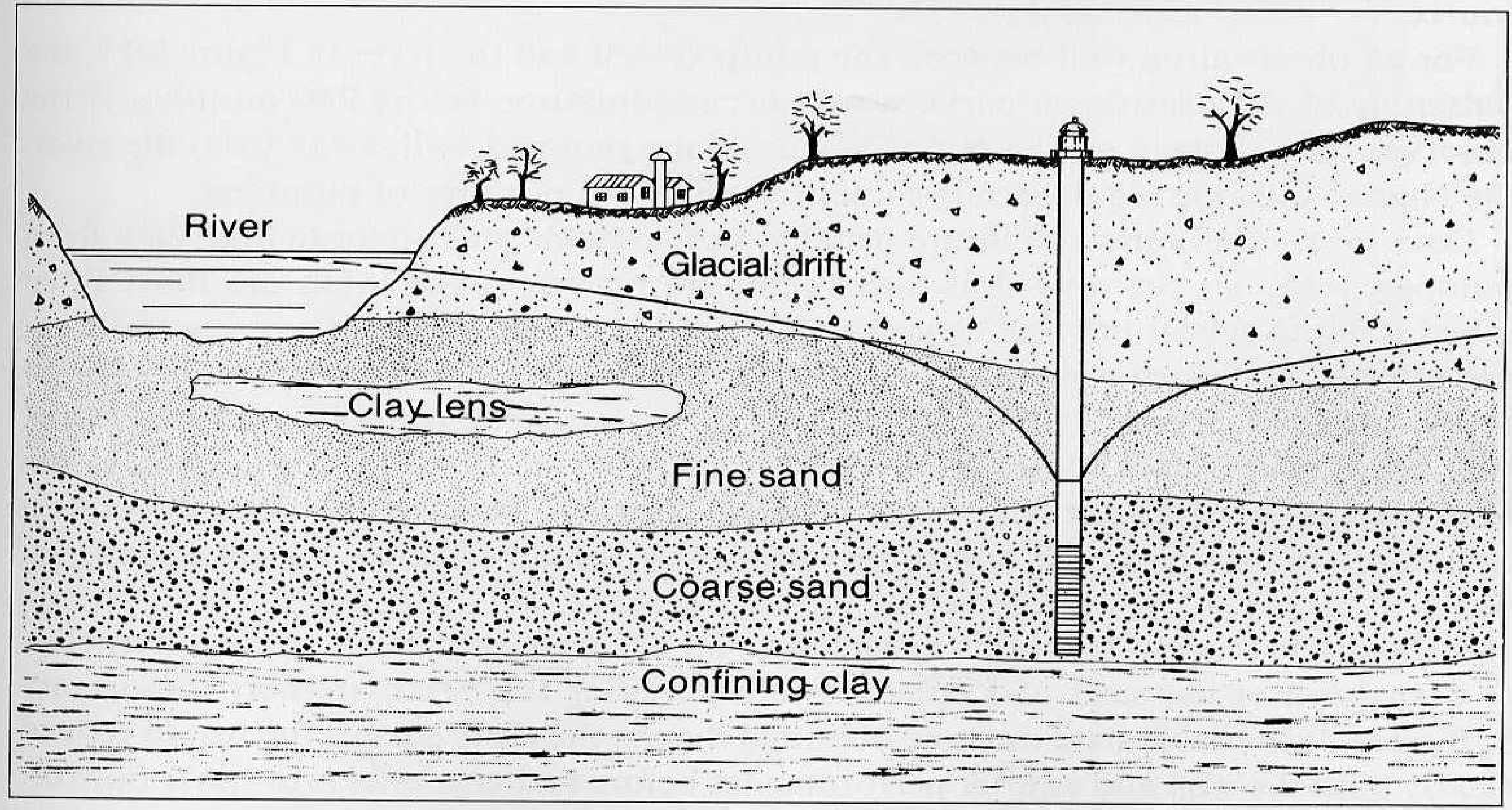
Plan View



Profile View

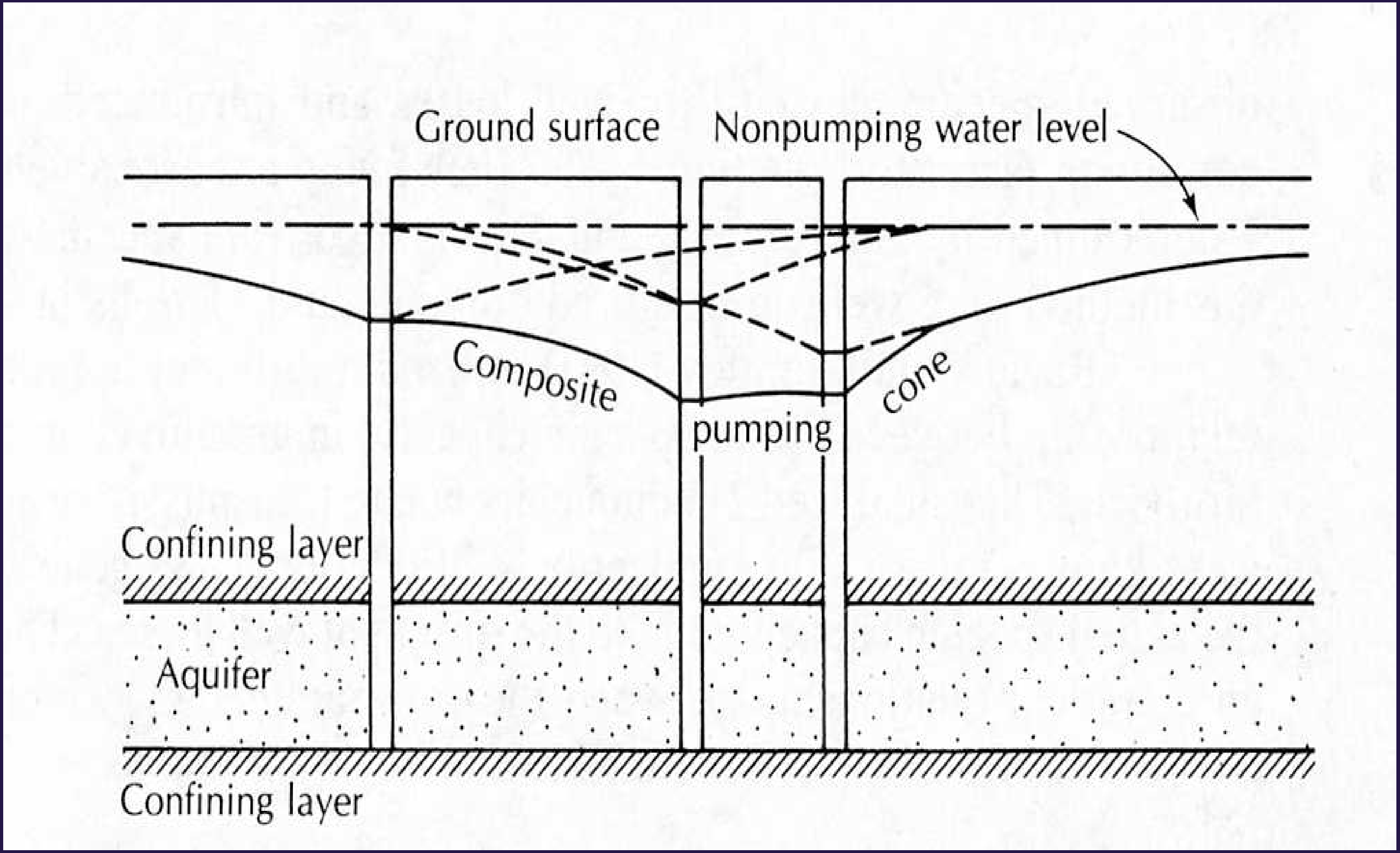


Well Equilibrium

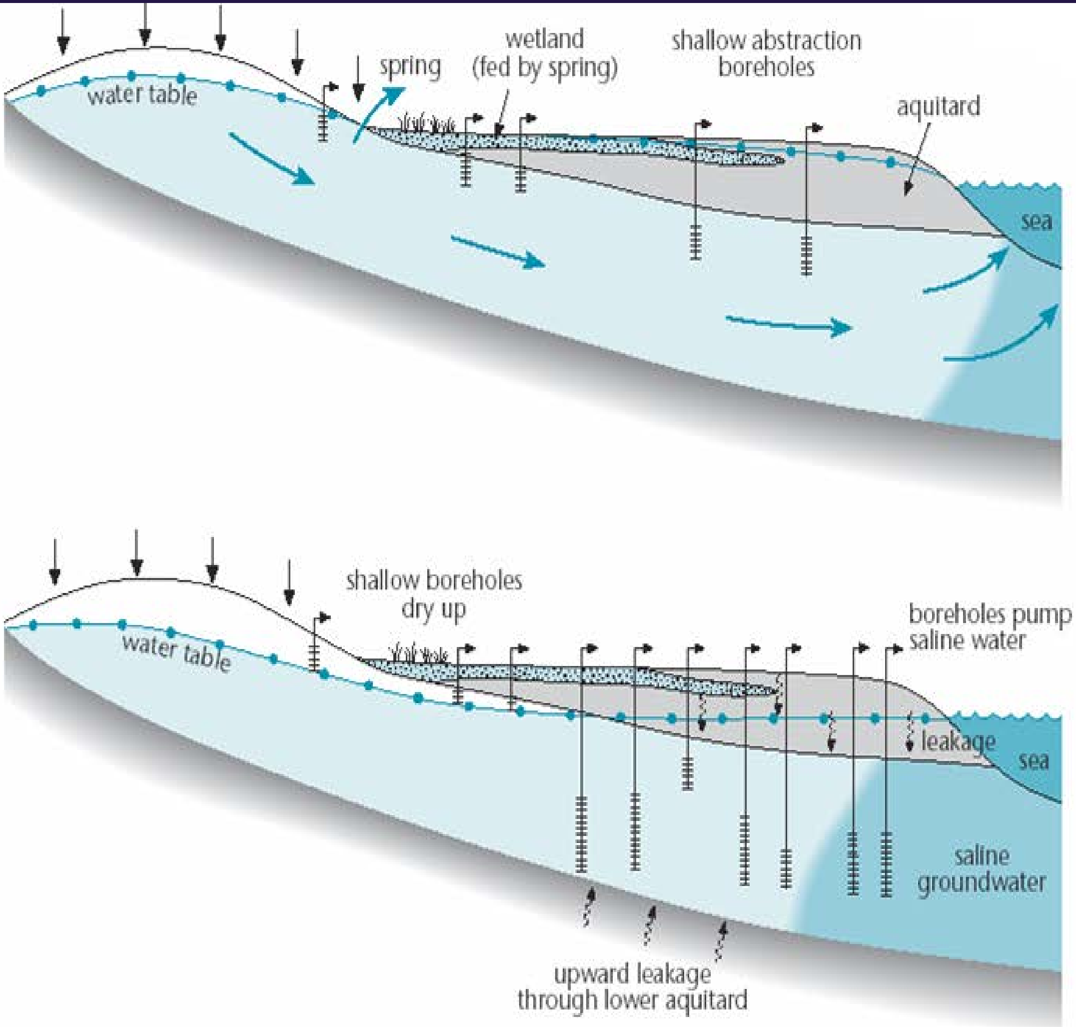


Source: Driscoll, 1986

Well Interference



Typical Impact of Excessive Pumping



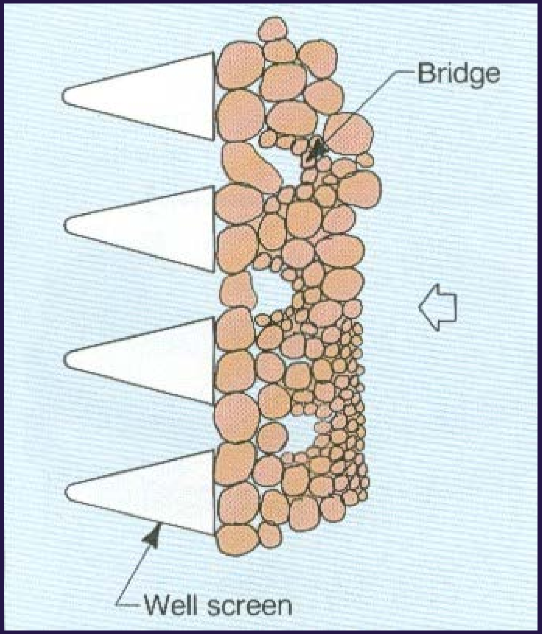
Stage A : Initial condition

- groundwater flows from outcrop to coast
- springs help maintain wetland
- limited abstraction from shallow boreholes occurrs

Stage B : Groundwater abstraction increases leading to:

- groundwater level decline in aquifer
- springs feeding wetland cease
- shallow wells dry up
- coastal boreholes become saline
- leakage through upper and lower aquitards (if present) begins

Well Troubleshooting

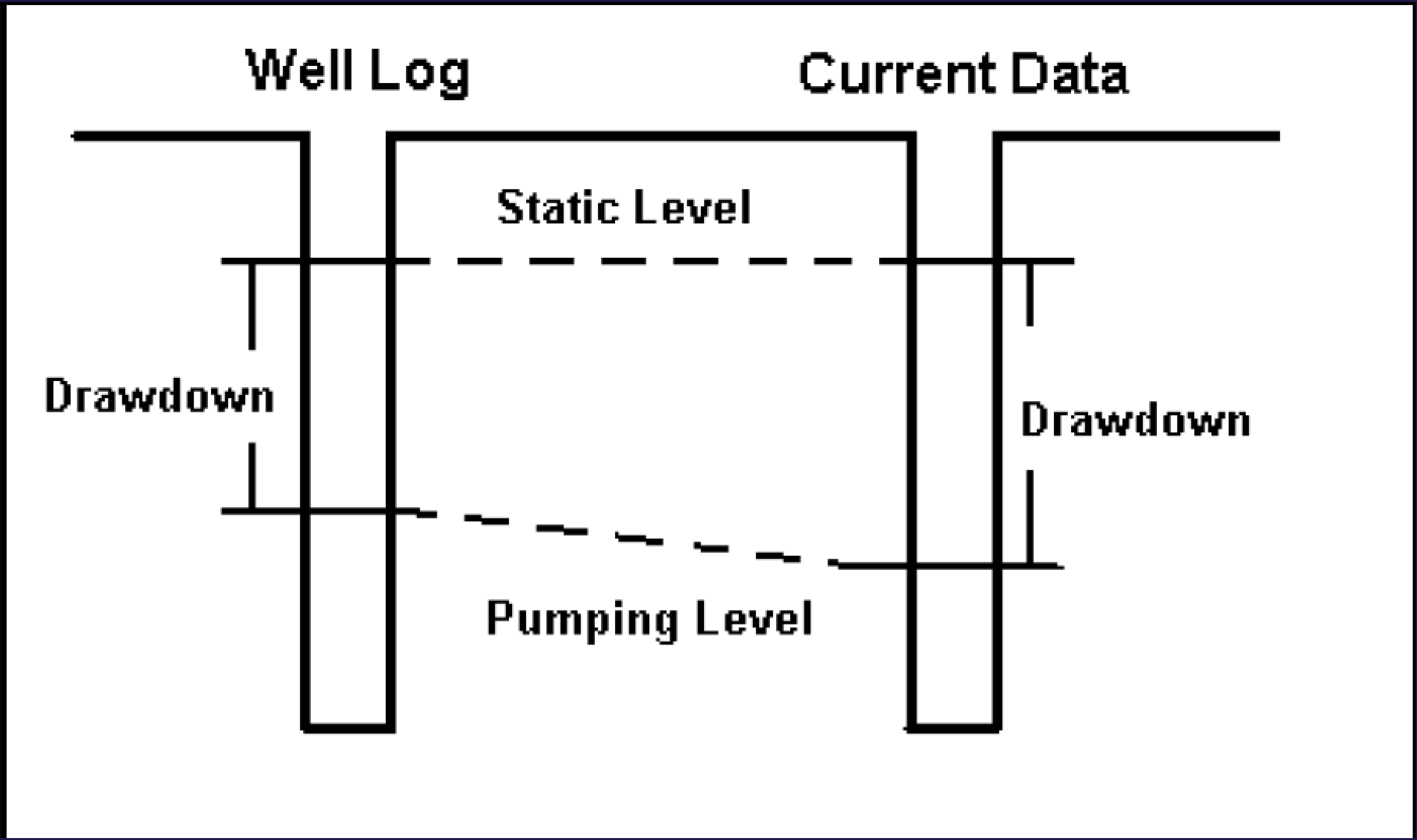


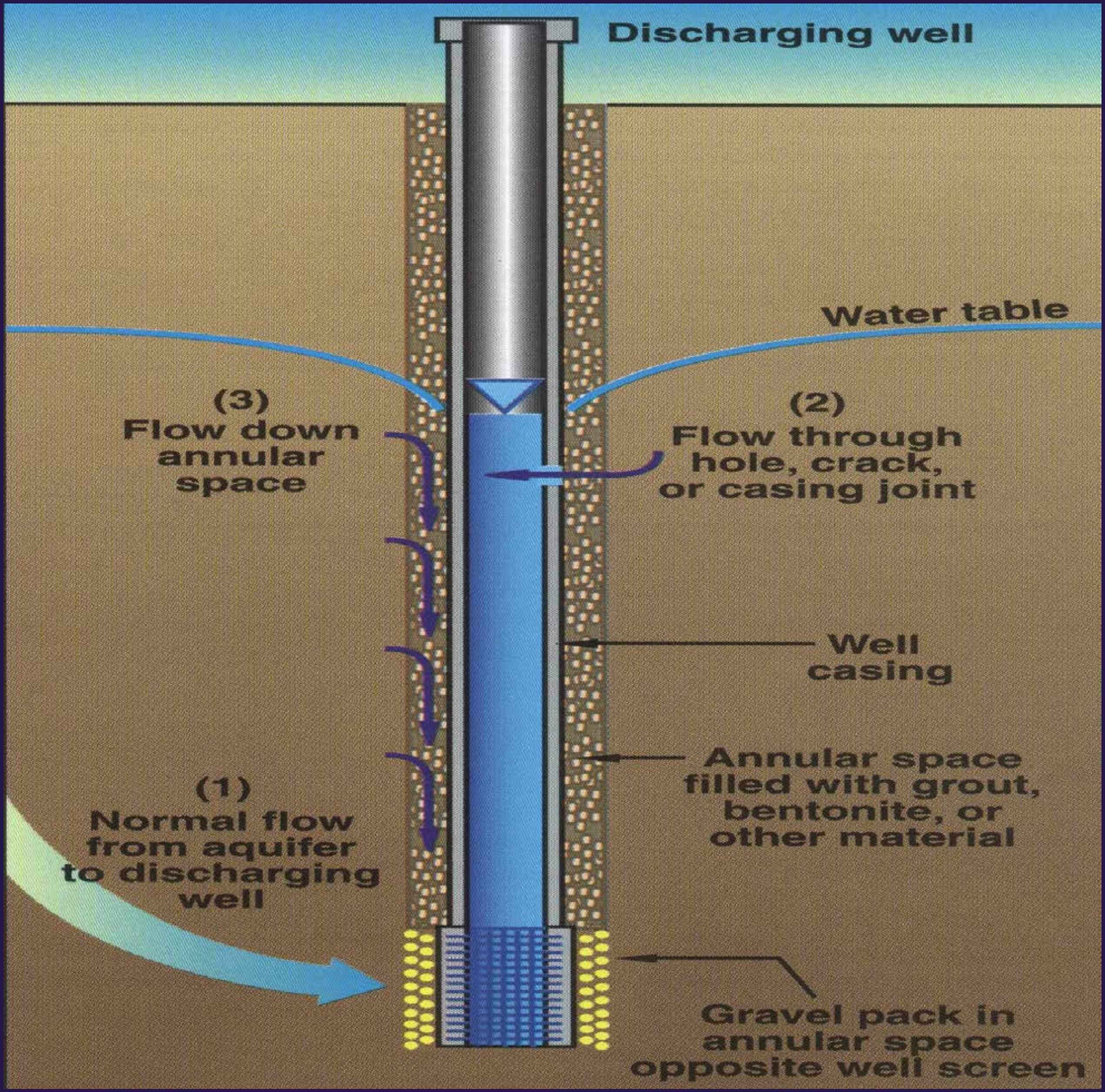
Causes of Well Problems

- Improper well design and construction
- Incomplete well development
- Borehole stability problems
- Encrustation buildup
- Biofouling
- Corrosion
- Aquifer problems
- Overpumping

Causes of Well Problems (cont.)

- Issues relating to improper well design/ construction and incomplete well development relate to the expertise and performance of the drilling contractor.
- Borehole stability problems, encrustation, corrosion, and aquifer problems are related to characteristics of the aquifer.
- Overpumping is caused by well users.


Well Log
Current Data
Static Level
Drawdown
Drawdown
Pumping Level


Discharging well
Water table
(3)
Flow down annular space
(2)
Flow through hole, crack, or casing joint
Well casing
Annular space filled with grout, bentonite, or other material
(1)
Normal flow from aquifer to discharging well
Gravel pack in annular space opposite well screen

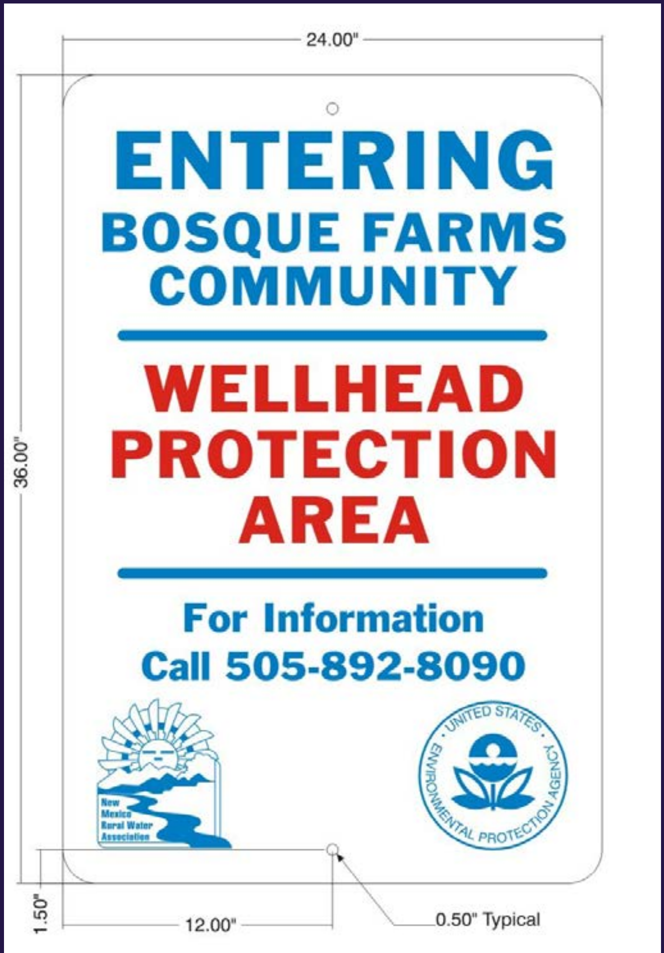
Well/Pump Related Issues

Problem	Issue
Static water level stays the same but the pumping level has dropped several feet	Aquifer Recovery Issues Clogged Screens Sand Bridging Iron Bacteria Lime Scaling
Static water level is the same but pumping water level has risen several feet, pump production has also decreased	Pump Related Problems Impeller clearance Line shaft stretch

Possible cause of reduced well yield	What to check for	How to correct
Pump and/or water system	Low pump production despite normal water level in well	Have a drilling contractor or industrial electrician troubleshoot
Aquifer depletion: • rate of withdrawal exceeds rate of recharge. • periods of drought can temporarily deplete shallow groundwater zones.	Compare current non-pumping static water level with the level at the time of well construction. A lower level confirms aquifer depletion	Reduce the water use. Drill a deeper well or one that taps into another aquifer.
Biofilm buildup in well casing, well screen, or pump intake.	Slime buildup on household plumbing fixtures.	Shock chlorinate the well and water system as required, usually once or twice a year.
Neighboring well interference	Check for significant drop in water levels in nearby wells.	Identify other nearby wells located in the same aquifer. Reduce pumping rates as required.
Mineral scale (encrustation) buildup on perforated well casing, well, or pump screen.	Scale formation on household plumbing fixtures.	Well should be cleaned by a drilling contractor by scouring, surging, and/or acid treatment.
Sediment plugging on the outside of perforated casing or screen.	Sediment in water, followed by sudden decline in yield.	Have a drilling contractor redevelop the well.
Collapse of well casing or borehole due to age of well.	Compare current depth of well with original records. A collapsed well will show a shallower depth than the original well data.	Recondition the well. If repair is not economical, plug the well and redrill.

What is Drinking Water Protection?

- Protection of drinking water sources
- Authorized by SDWA Section 1428 of the 1986 amendments
- EPA-approved, state-designed wellhead protection plans can receive federal funding to protect groundwater sources



Drinking Water Protection

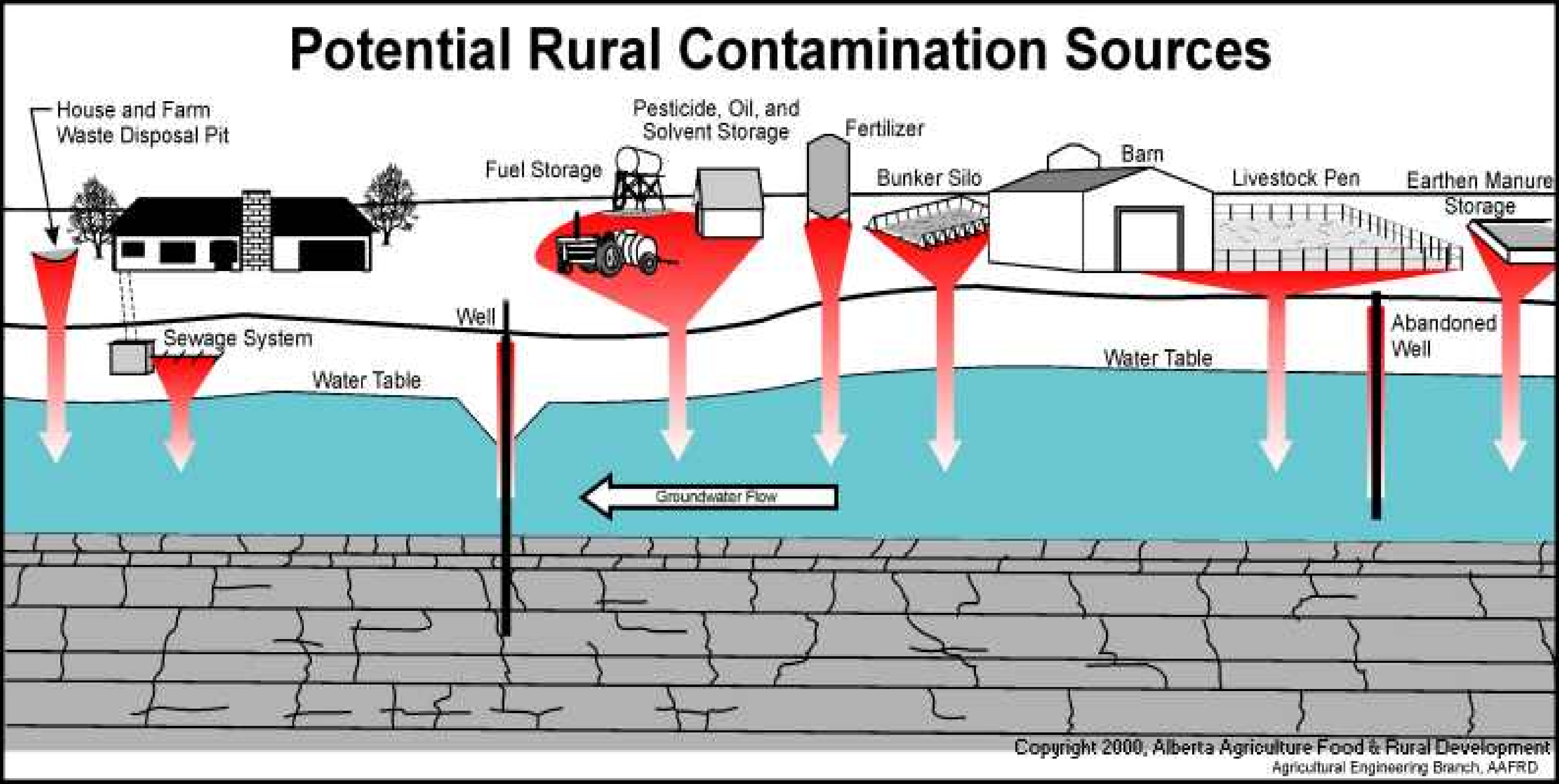
- Efforts to protect drinking water sources
  - Groundwater
  - Surface water
- Why protect drinking water
  - Public health protection and confidence
  - Economic benefits
  - Environmental benefits
  - Cultural preservation

Economic Benefit?

- Typical costs to deal with contaminated groundwater for a small city in Ohio (PCE contaminating a sand-and-gravel aquifer) (1995 Ohio EPA figures):
  - Soil remediation (one time): $800,000
  - Groundwater monitoring (per year): $15,000
  - Electricity for air strippers (per year): $6,000
  - Two new wells: $50,000

Cost for one year: $871,000

Groundwater Contamination



Drinking Water Protection

- Step 1: Develop a community planning team
- Step 2: Delineate the protection area
- Step 3: Inventory potential sources of contamination (PSOCs)
- Step 4: Manage the protection area
- Step 5: Contingency planning

Step 1: Planning Team

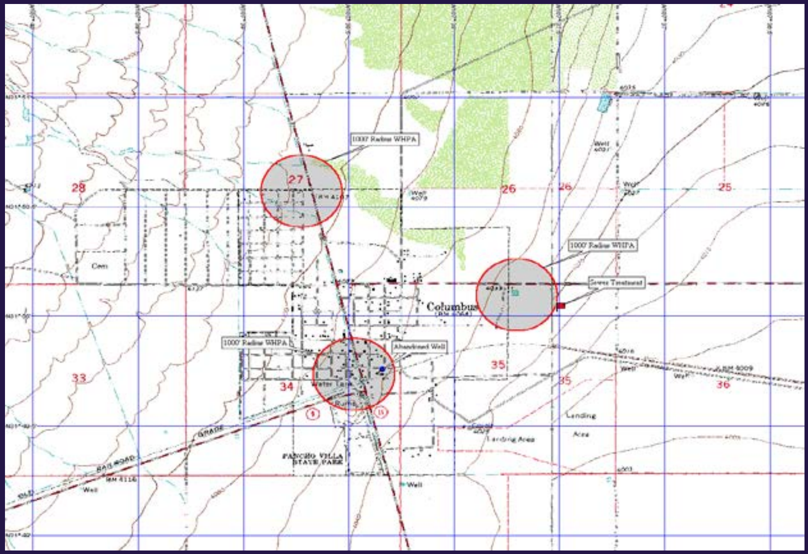
- Purpose
  - Gather information
  - Make decisions
  - Public education
- Key decision makers of tribal community and departments
- Facilitated action oriented meetings

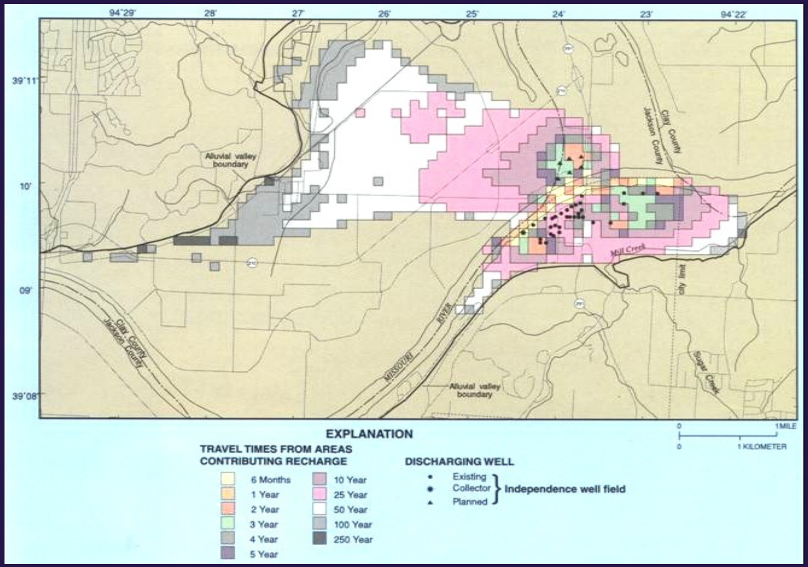
Step 1: Planning Team (cont.)

- Invested in planning from the drawing board to protection activities
- Interdepartmental collaboration

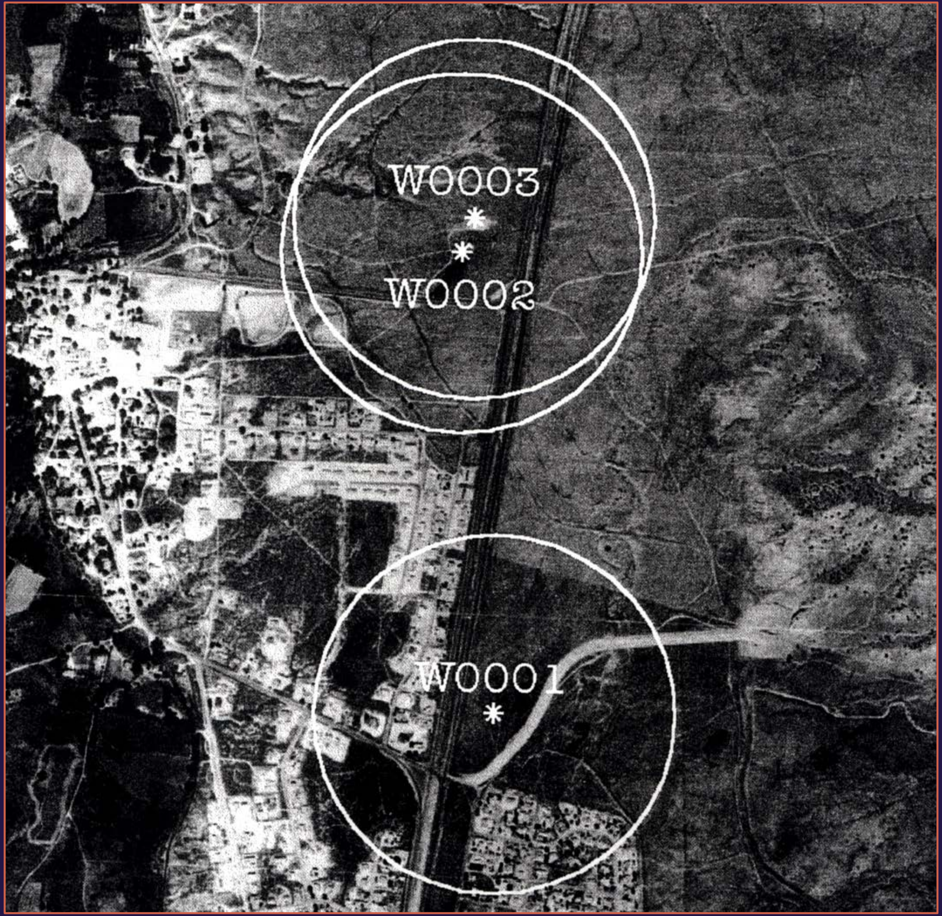
Step 2: Delineate Protection Area(s)

- Method
  - Fixed radius
    - Arbitrary
    - Calculated
  - Time of travel
    - Analytical
    - Hydrogeologic mapping
    - Flow models
- Site and resource specific





Source Water Protection Area Delineation (Groundwater)



- EPA source water assessments
- Hydrologic analysis
- Tribal programs dedicated to water resources protection
- Utility department planning programs

Step 3: PSOC Inventory

- Identify and map PSOCs within delineated protection area

Arroyo Dumping

- Potential drinking water supply contaminants
  - Organic/inorganic chemicals
  - Metals
  - Oils
  - Nitrate

Abandoned Wells

- Potential drinking water supply contaminants
  - Common nearby activities may degrade water quality
  - Runoff poses threats

Grazing

- Potential drinking water supply contaminants
  - Nitrate
  - Sprays
  - Dips
  - Bacteria
  - Fungus
  - Viruses

Feed Lots and Animal Feeding Pens

- Potential drinking water supply contaminants
  - Nitrate
  - Phosphate
  - Chloride
  - Bacteria
  - Fungus
  - Viruses

Gas Stations

- Potential drinking water supply contaminants
  - Gasoline
  - Oils
  - Solvents
  - Wastes

Failed Septic Systems

- Potential drinking water supply contaminants
  - Nitrate
  - Bacteria
  - Fungus
  - Viruses
  - Turbidity

Step 4: Manage the Protection Area

- Education, education, education . . .
- Best management practices (BMPs)
- Overlay zoning, ordinances, land purchase

Best Management Practices (BMPs)

- Practices to prevent contamination of groundwater and surface water used or potentially used as sources of drinking water
- Protection measures from the first barrier to drinking water protection

BMP Examples

Wellhead Integrity Improvements

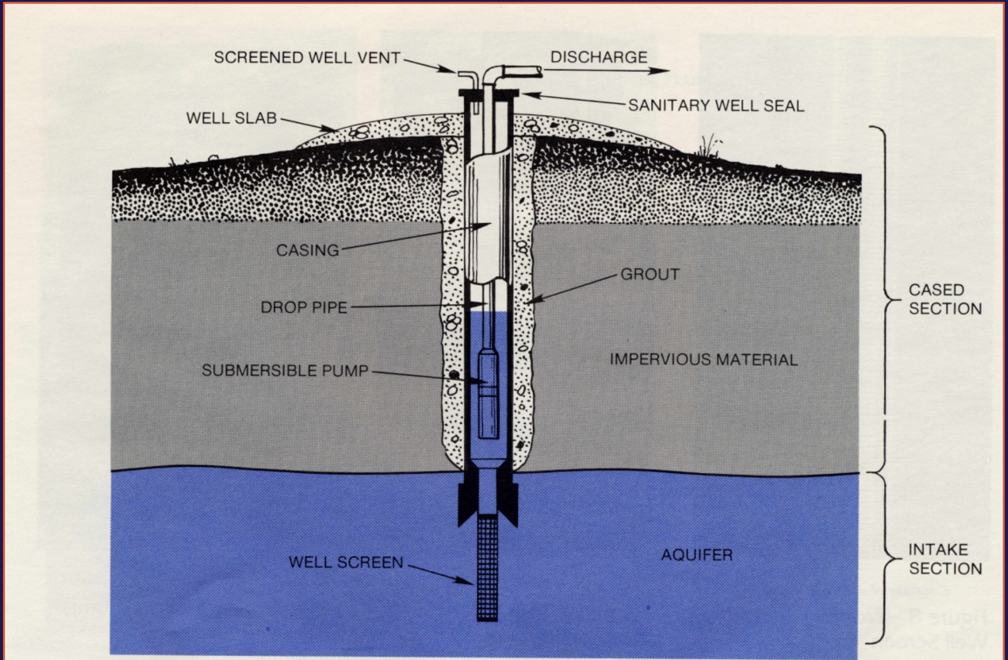


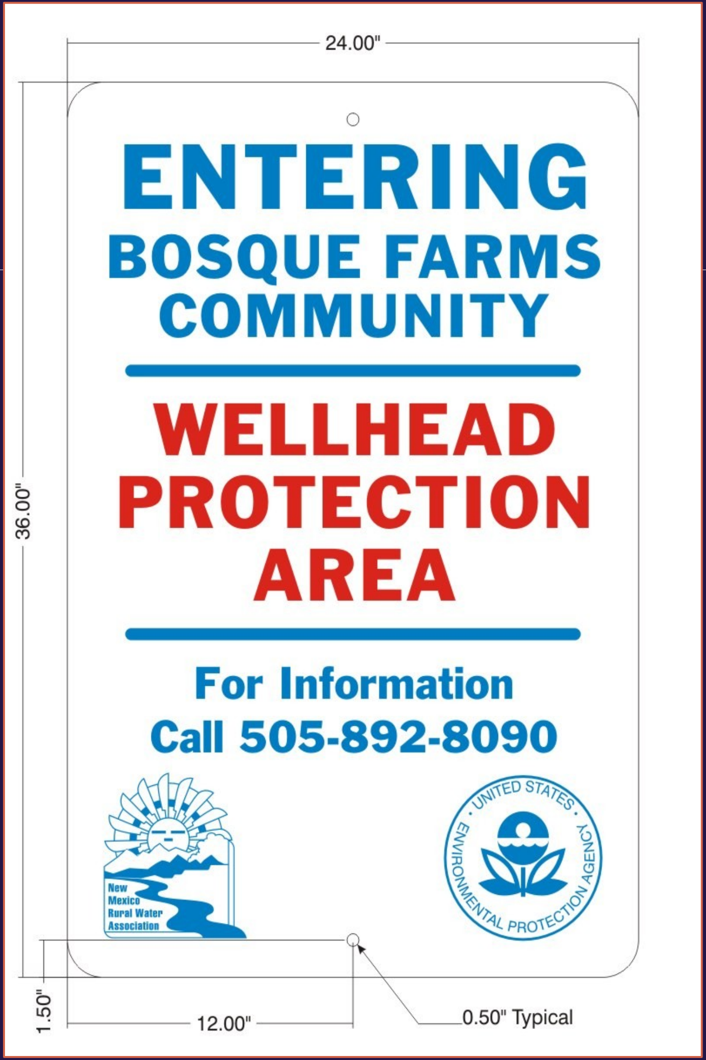
Figure 7 Major Sections of a Well

Regulations and Permits

Backfilling a UST installation in a lined pit

- Underground storage tank (UST) permitting
  - Proper installation
  - Corrosion protection
  - Spill prevention
  - Overfill protection
  - Leak detection
  - Proper closure

Emergency Response Planning



- Highway and local road spill plan
  - Contact state and federal highway departments to develop a spill plan and let them know that your source water area is located in a highway right-of-way

Water Source Improvements

- Wellhouse improvements
- Well rehabilitation
- New well development
- New treatment techniques
- Operator training in water source monitoring

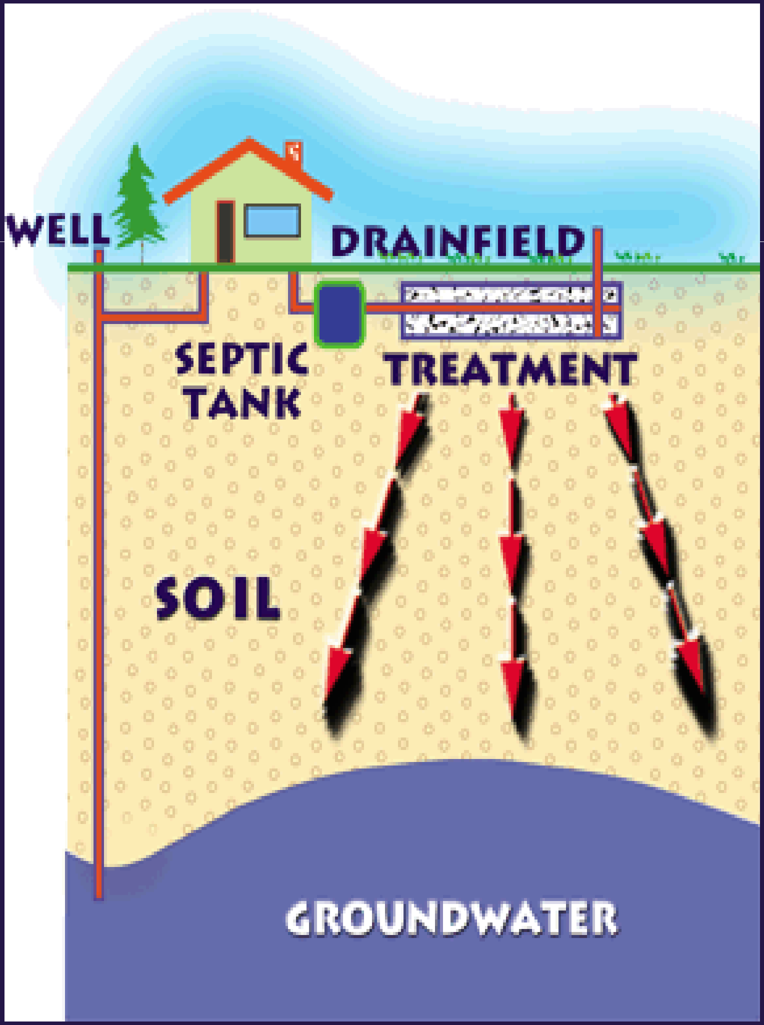
Good Housekeeping Practices

- Household hazardous waste eradication program
  - Conduct a chemical audit
  - Implement a chemical management plan
  - Community hazardous waste cleanup
  - Store chemicals properly
  - Do not empty in sinks or drains

Abandoned Wells

- Proper capping/plugging
- Minimize water infiltration

Septic Systems



- Proper use
- Zoning/land use
- Conservation

Step 5: Contingency Planning

- Includes water supply planning to provide short- and long-term alternatives for water sources (including funding) and emergency spill response

Food for Thought

- Certain kinds of human activity and land use involve contamination that can enter the water cycle or drinking water well directly and could then show up in community water systems.

Drinking Water Protection