Ground Water and Wells

Basic (Geo)Science for Sustainable a Future

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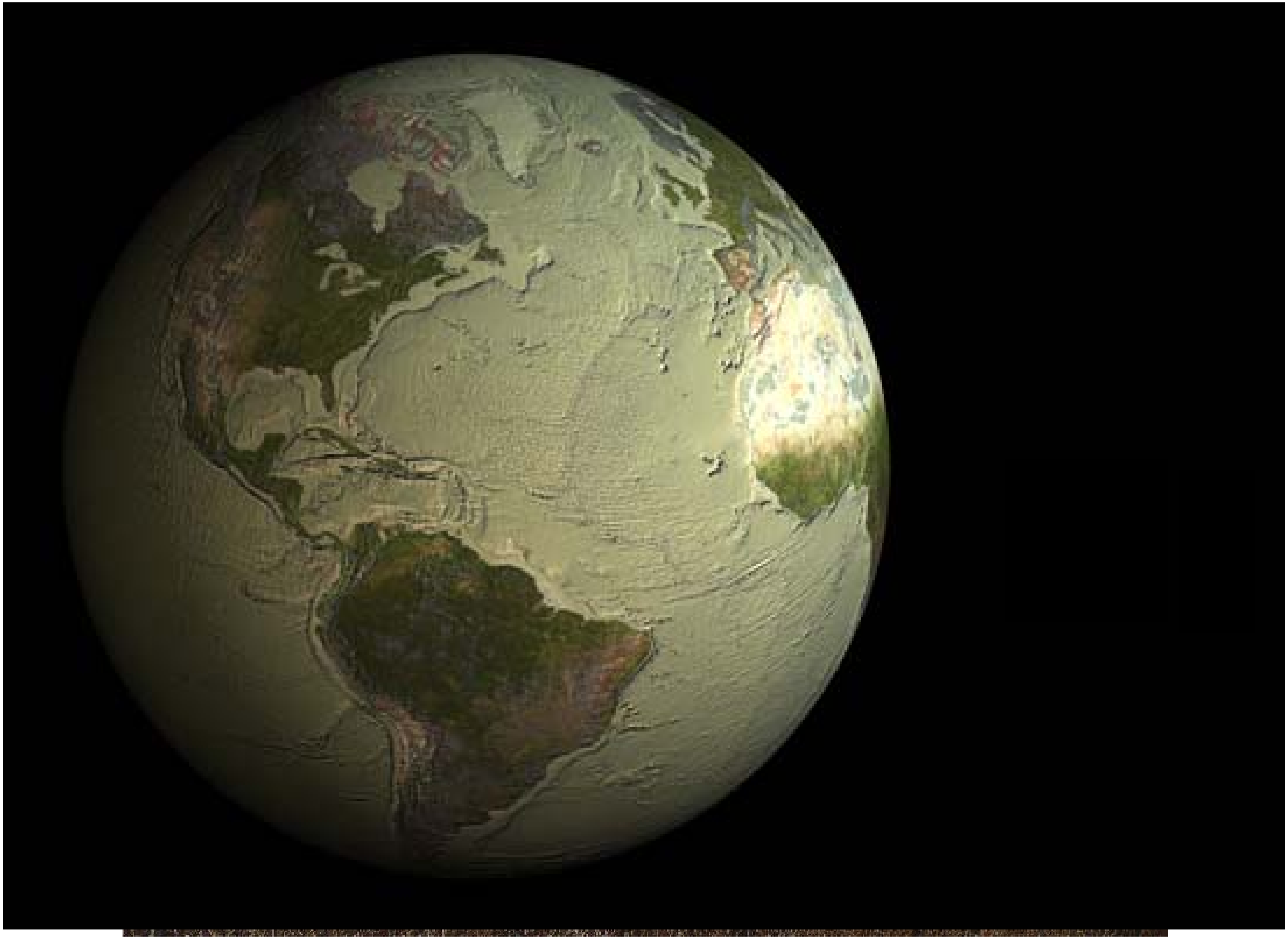
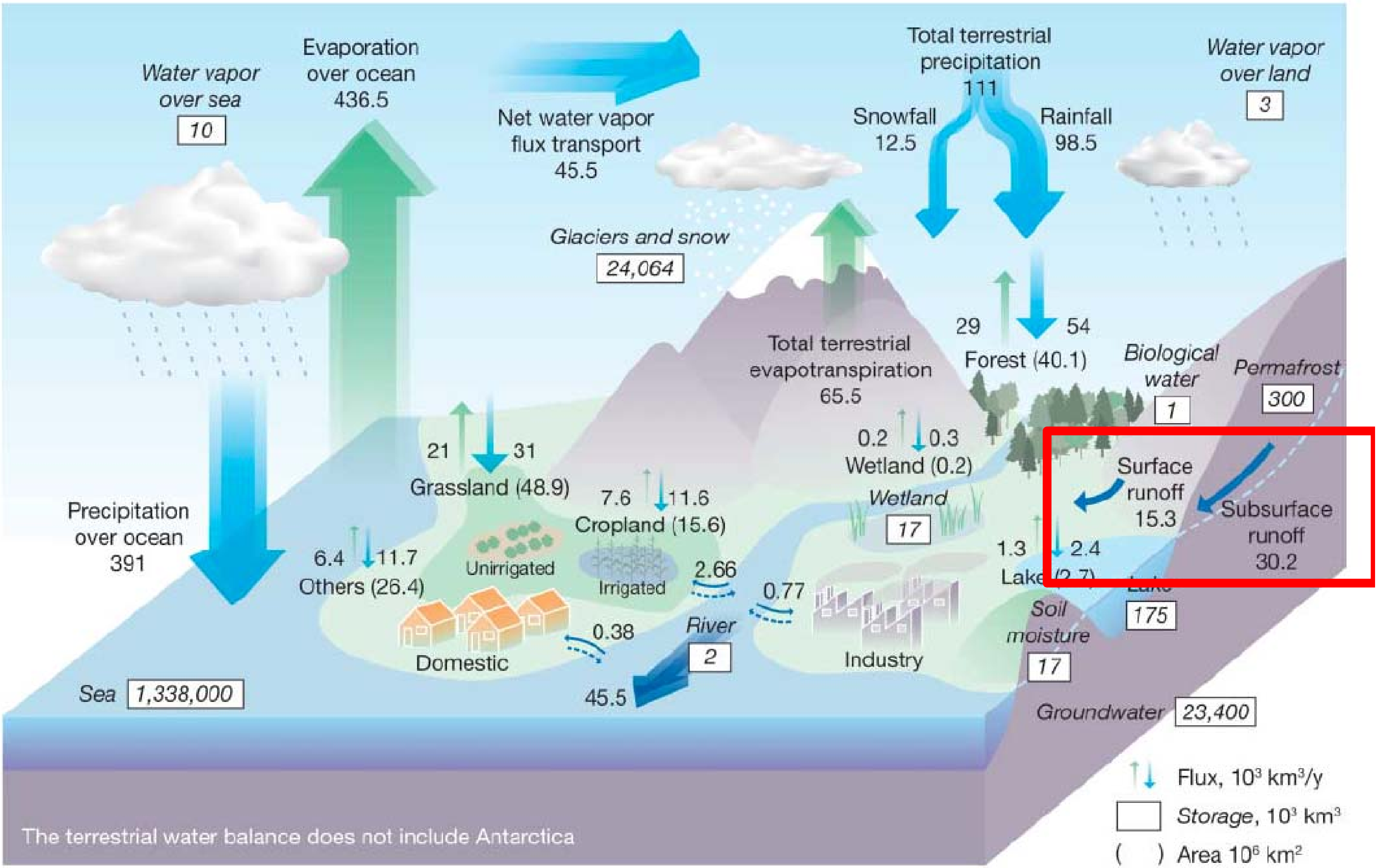
Your tasked with locating properties/land to purchase for a high yield (1000 gpm) well for the town of Sunderland, MA and Lakeside, NE on this map. Where would you put it and why? Choose 2 locations.

What Factors are Important?

- Water Quantity
  - Geology/Hydrology Determines this
  - Impacts on Environment
  - Safe and Sustainable Yields
- Water Quality
  - Natural Water Chemistry
  - Filtration
  - Treatment
- Economic
  - Cost of getting water to users
  - Delivery and Distribution



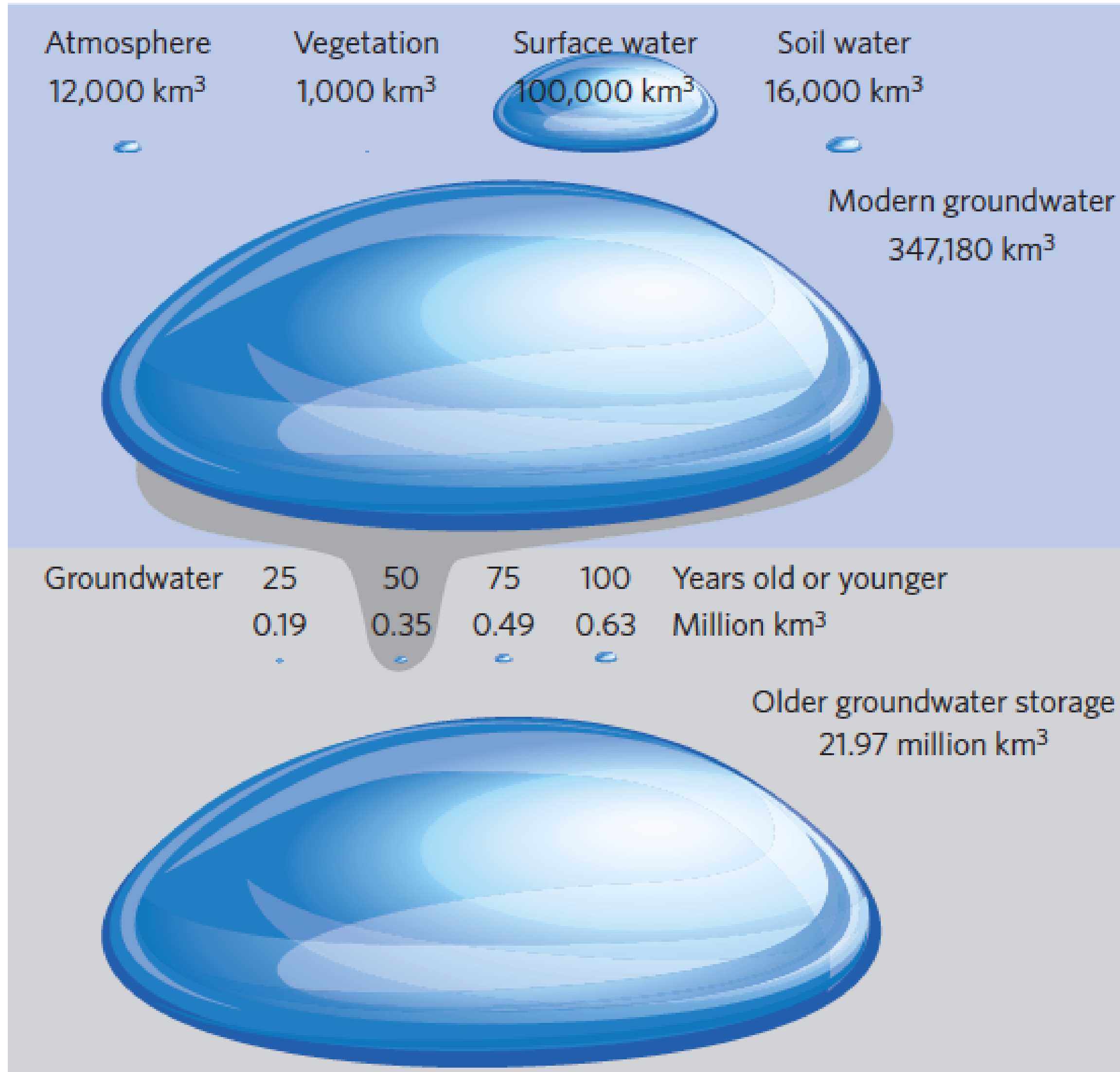


Globally – Groundwater provides at least 2/3 of the water to global stream discharge

Global Hydrological Cycles and World Water Resources
Taikan Oki and Shinjiro Kanae
Science **313**, 1068 (2006);

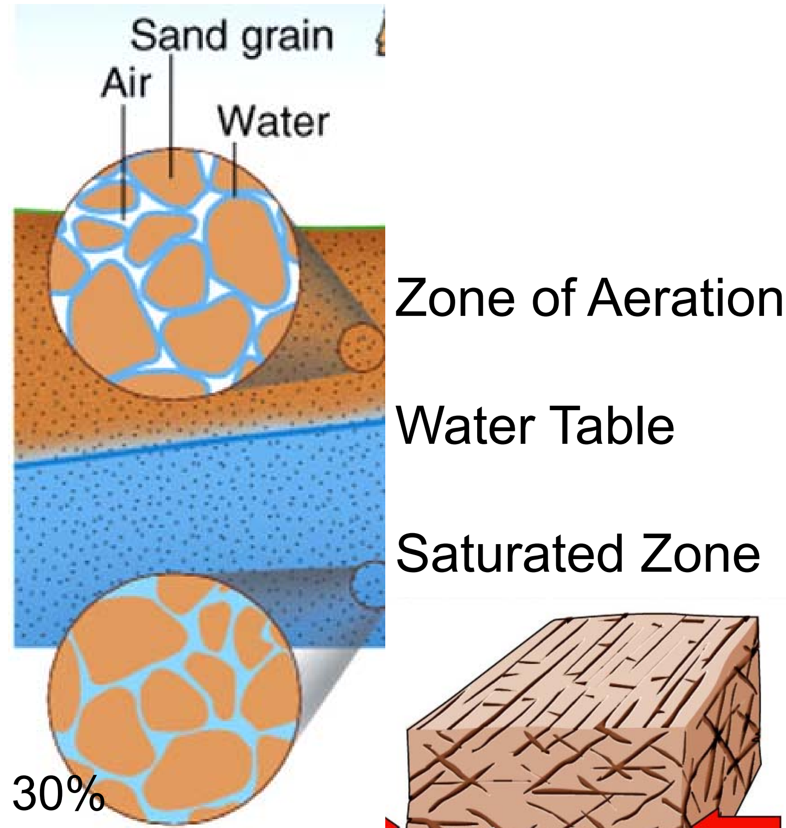
nature geoscience
ARTICLES
PUBLISHED ONLINE: 16 NOVEMBER 2015 | DOI: 10.1038/NGEO2590

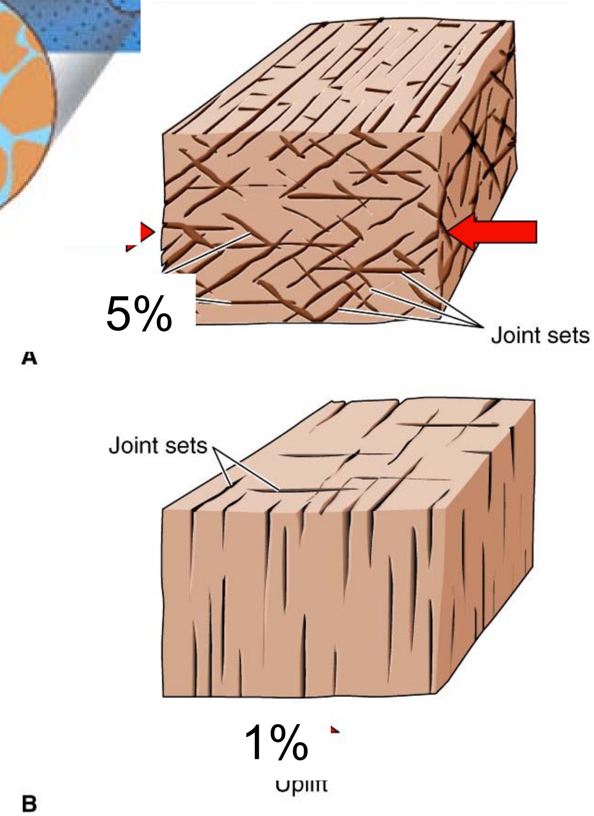
The global volume and distribution of modern groundwater



Porosity and Permeability

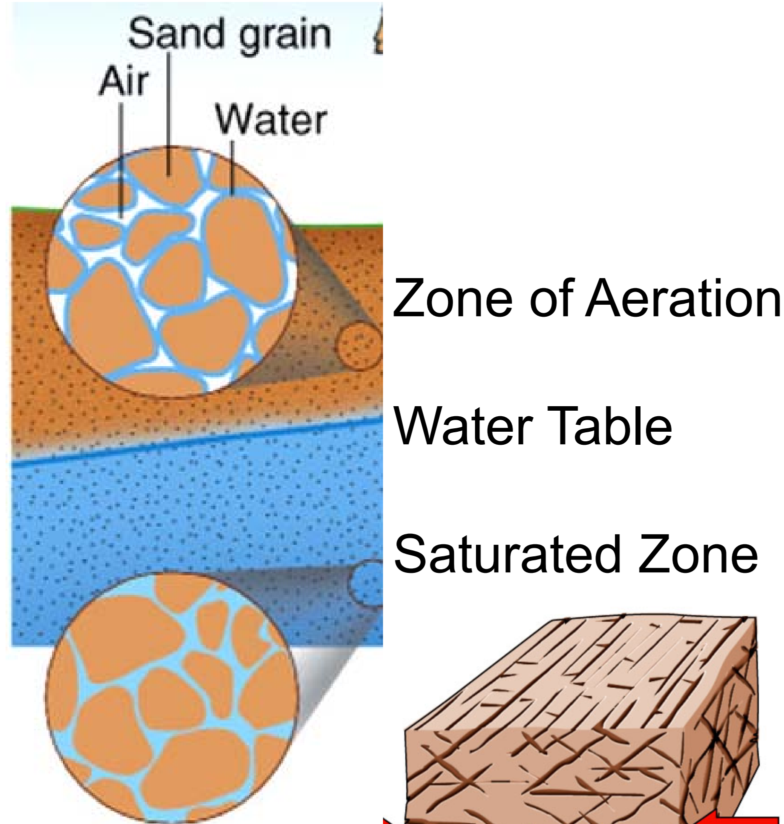
- **Porosity**: Percent of volume that is void space.
    - **Sediment**: Determined by how tightly packed and how clean (silt and clay), (usually between 20 and 40%)
    - **Rock**: Determined by size and number of fractures (most often very low, <5%)

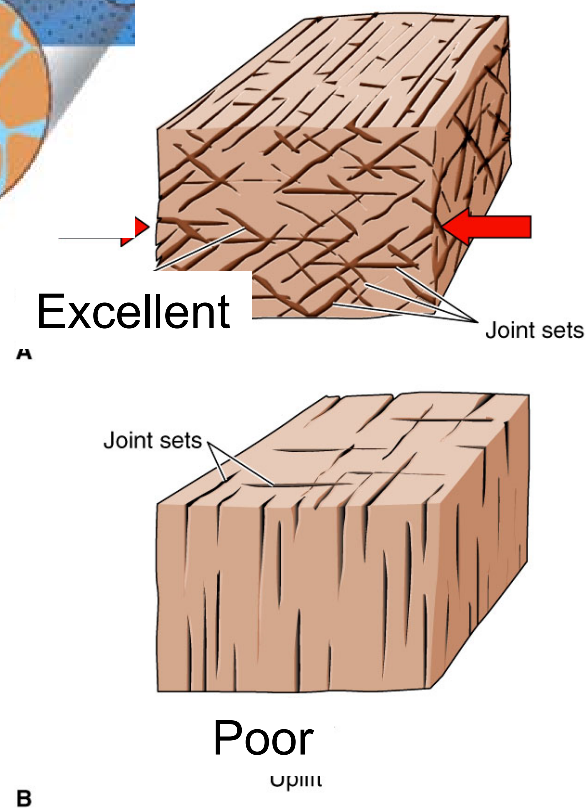




Porosity and Permeability

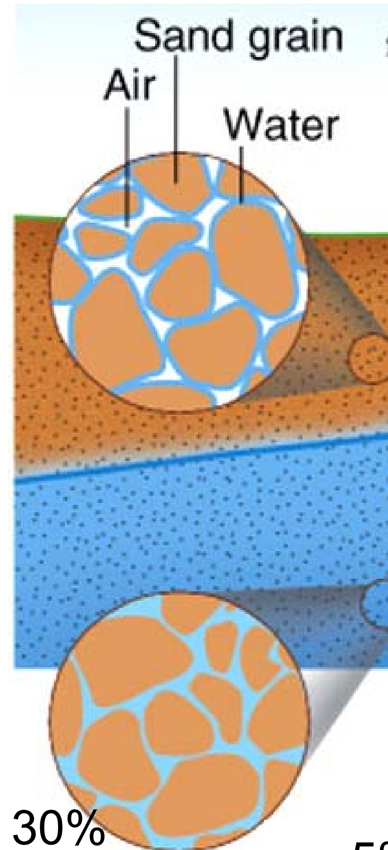
- **Permeability**: Ease with which water will flow through a porous material
  - **Sediment**: Proportional to sediment size
    - Gravel→Excellent
    - Sand→Good
    - Silt→Moderate
    - Clay→Poor
  - **Rock**: Proportional to fracture size and number. Can be good to excellent (even with low porosity)





Porosity and Permeability

- Permeability is **not proportional** to porosity.



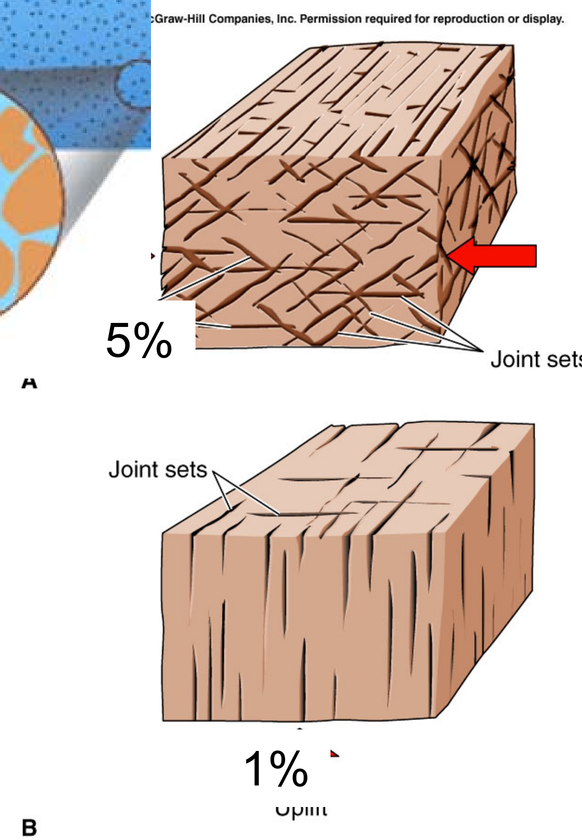
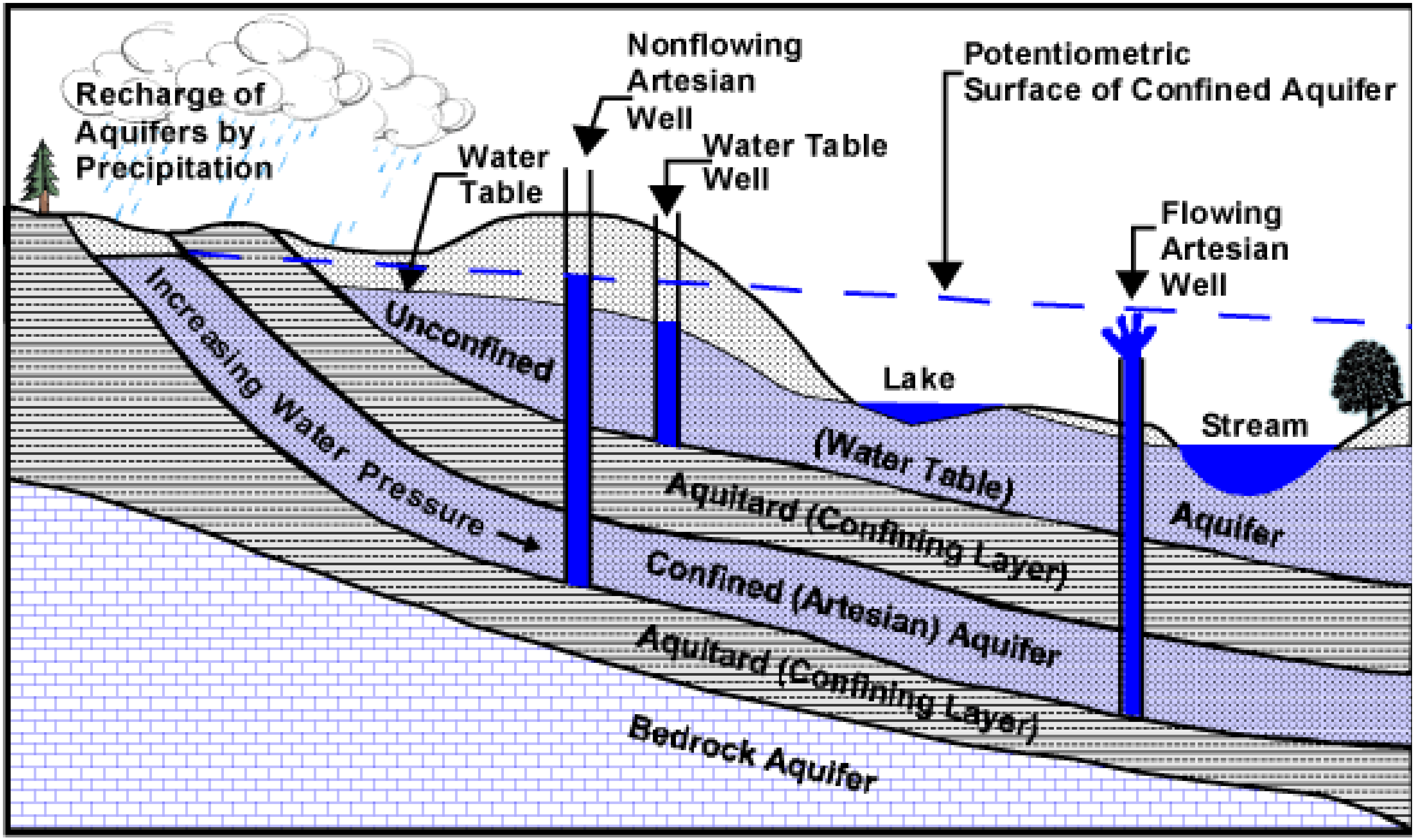


Table 13.1

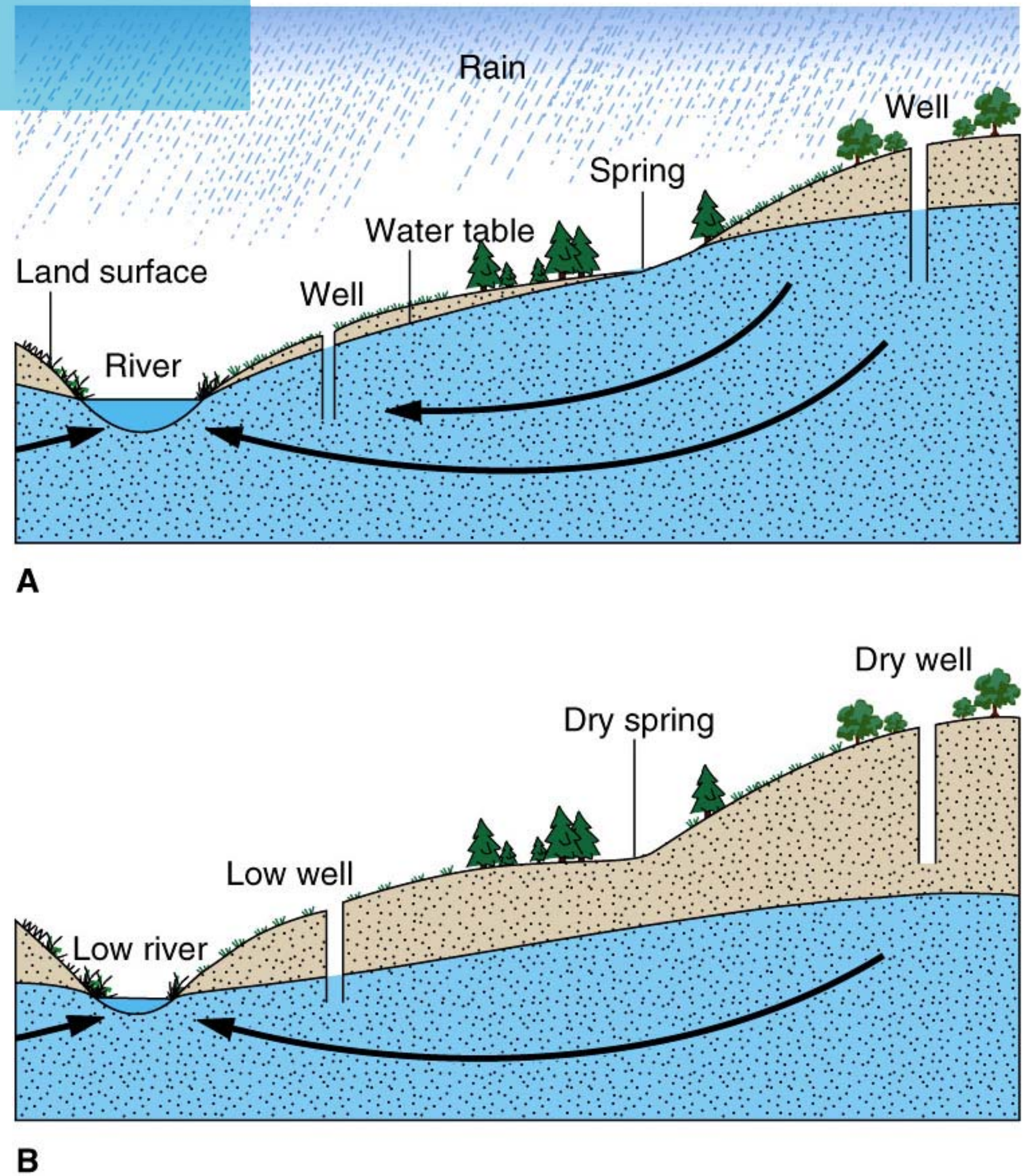
Sediment	Porosity (%)	Permeability
Gravel	25 to 40	excellent
Sand (clean)	30 to 50	good to excellent
Silt	35 to 50	moderate
Clay	35 to 80	poor
Glacial till	10 to 20	poor to moderate

Some ground water basics …



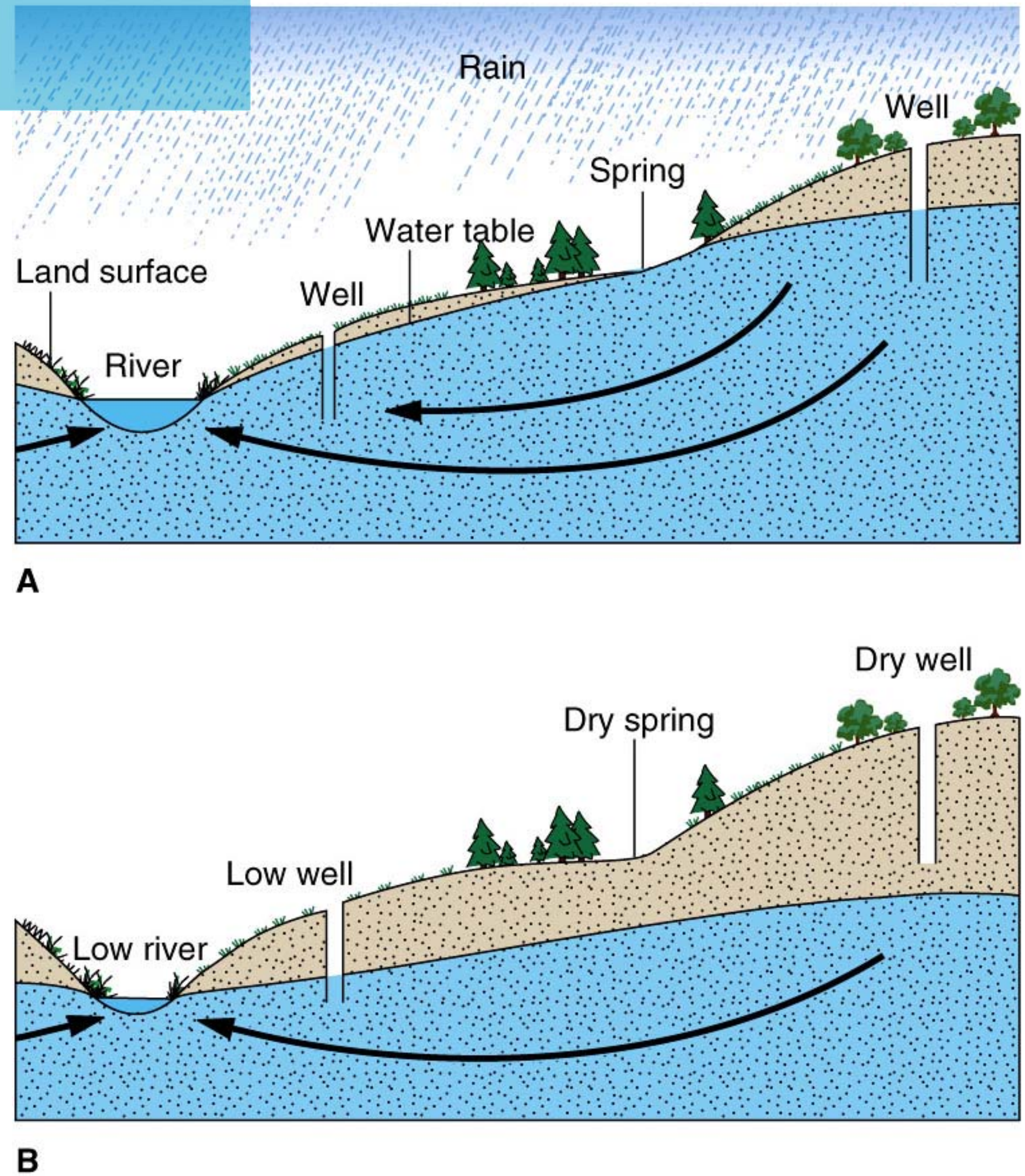
Natural Water Table Fluctuations

- Infiltration
  - Recharges ground water
  - Raises water table
  - Provides water to springs, streams and wells
- Reduction of infiltration causes water table to drop



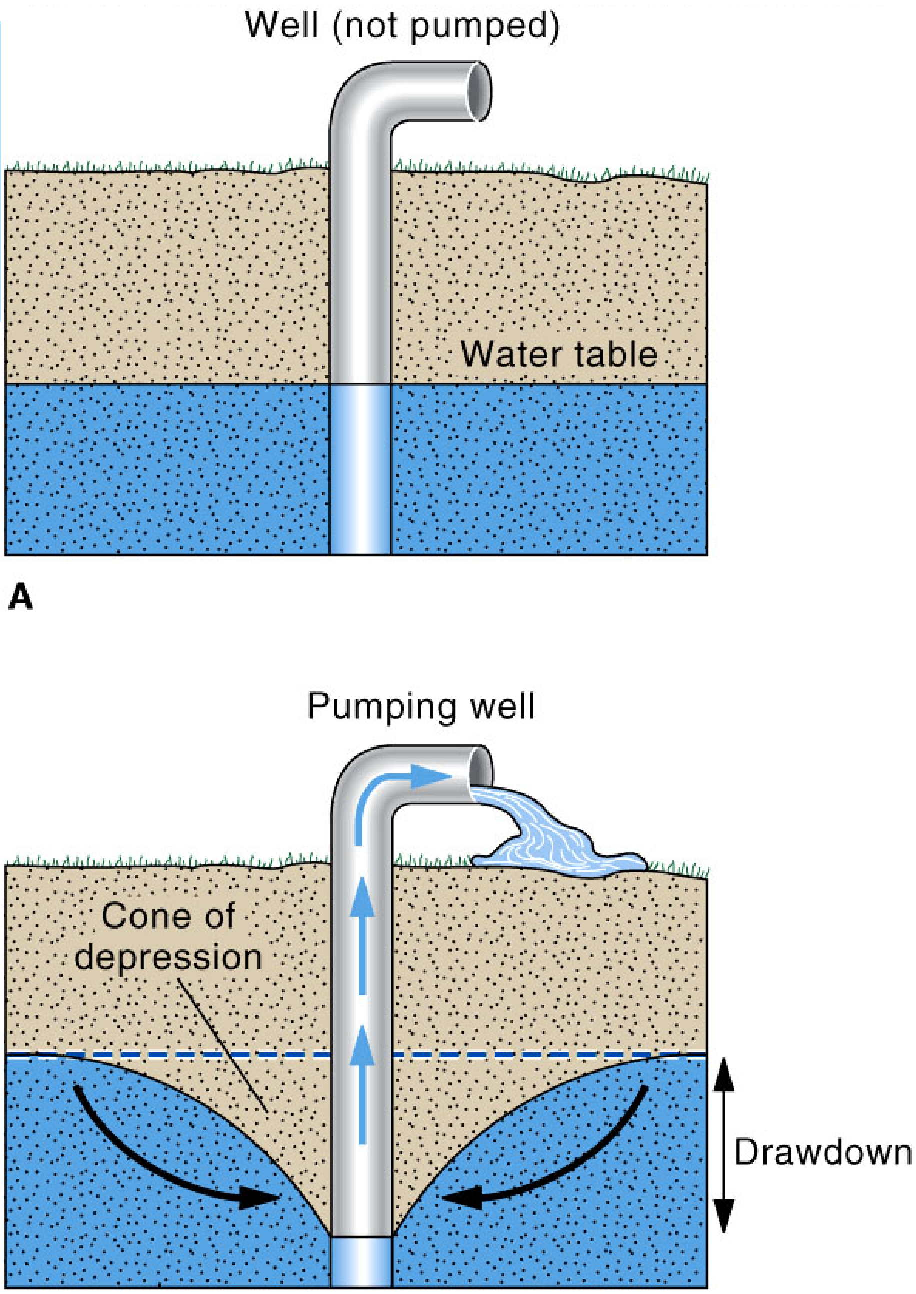
Natural Water Table Fluctuations

- Reduction of infiltration causes water table to drop
  - Wells go dry
  - Springs go dry
  - Discharge of rivers drops
- Artificial causes
  - Pavement
  - Drainage



Effects of Pumping Wells

- Pumping wells
  - Accelerates flow near well
  - May reverse ground-water flow
  - Causes water table drawdown
  - Forms a cone of depression



Effects of Pumping Wells

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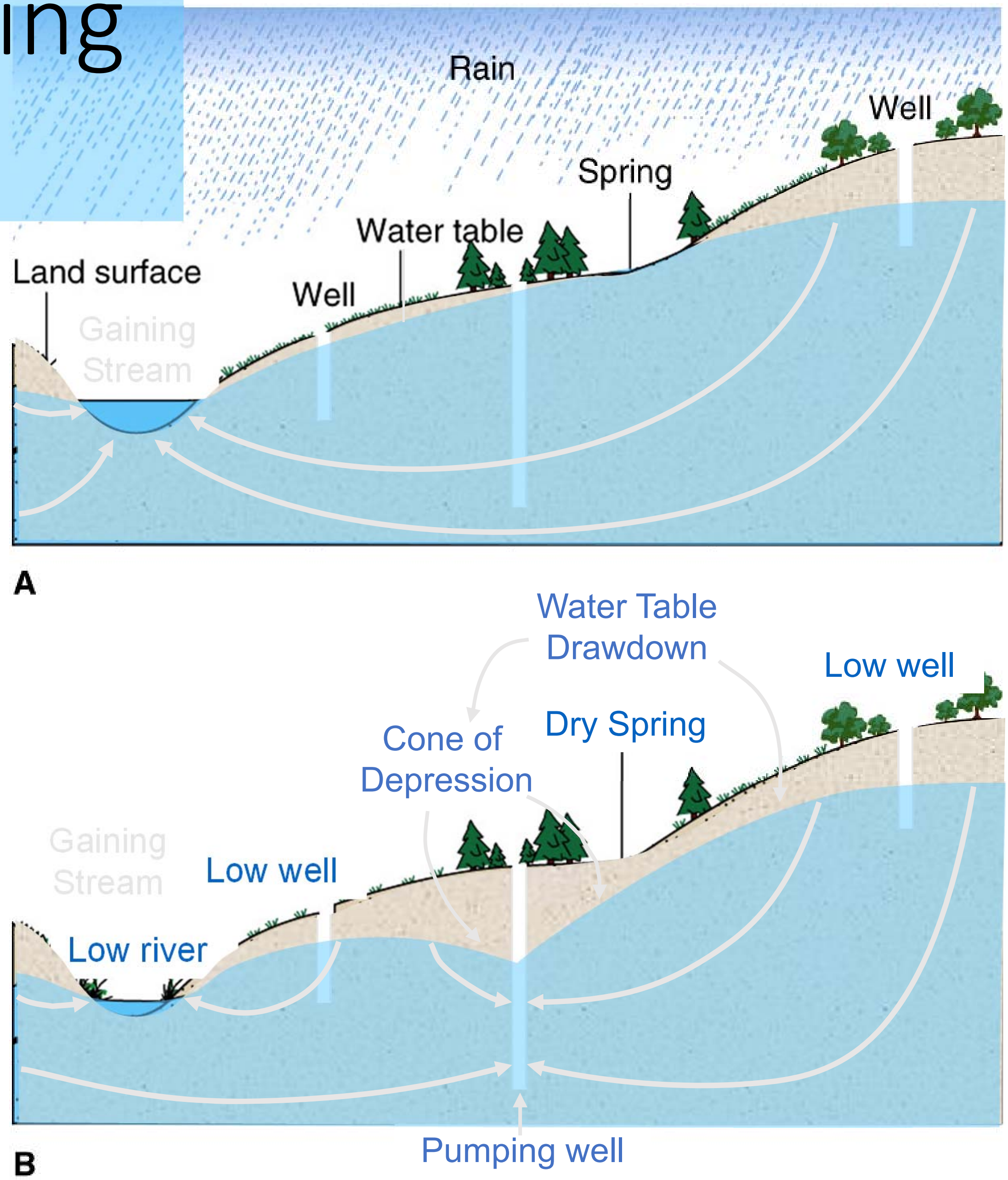
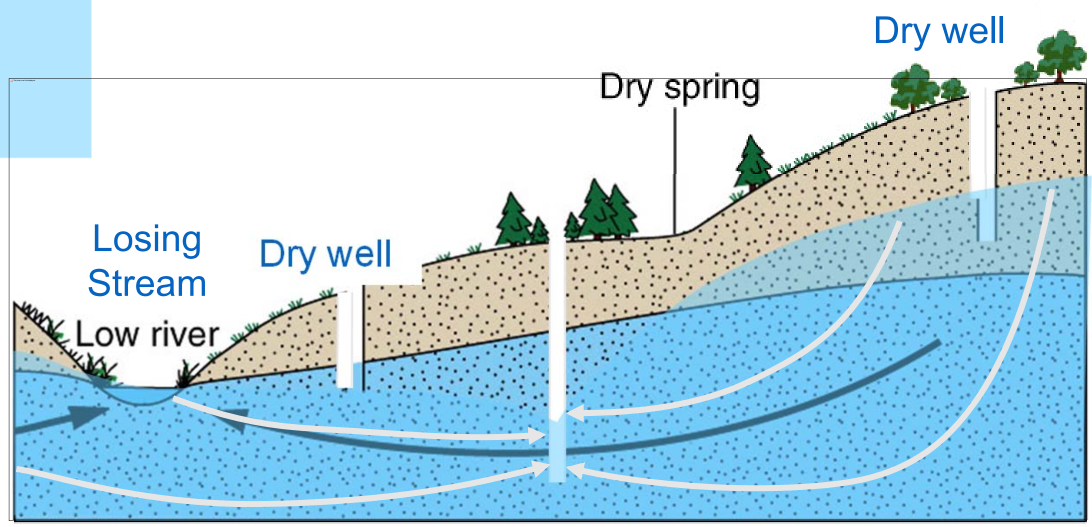
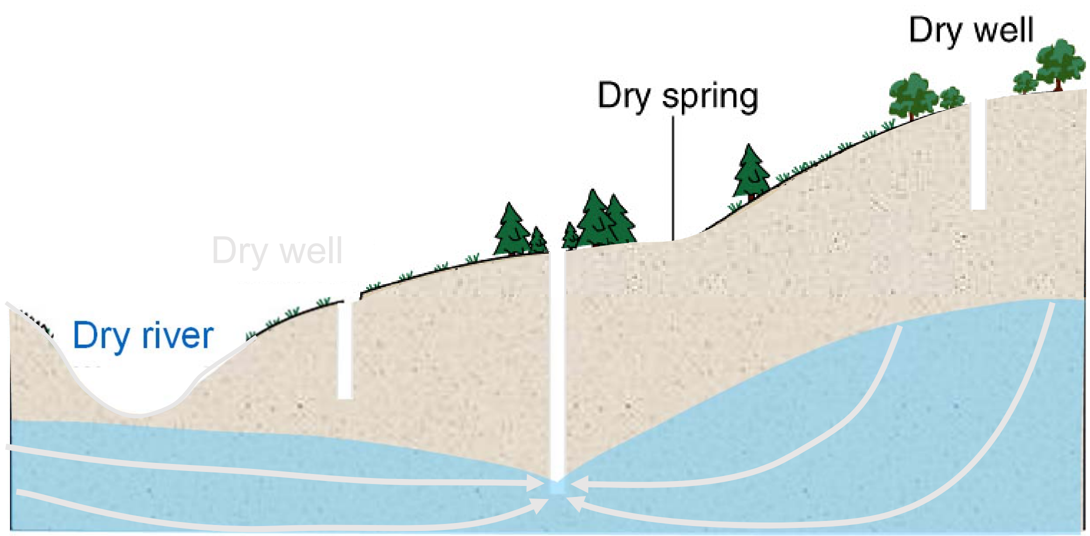


Effects of Pumping Wells

- Continued water-table drawdown
  - May dry up springs and wells
  - May reverse flow of rivers (and may contaminate aquifer)
  - May dry up rivers and wetlands



B

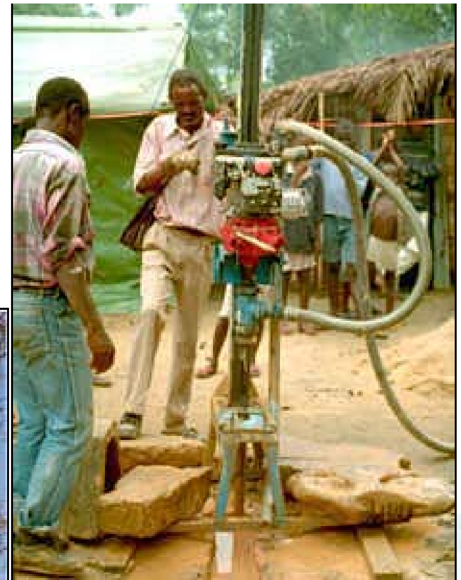


B

Groundwater exploration & exploitation

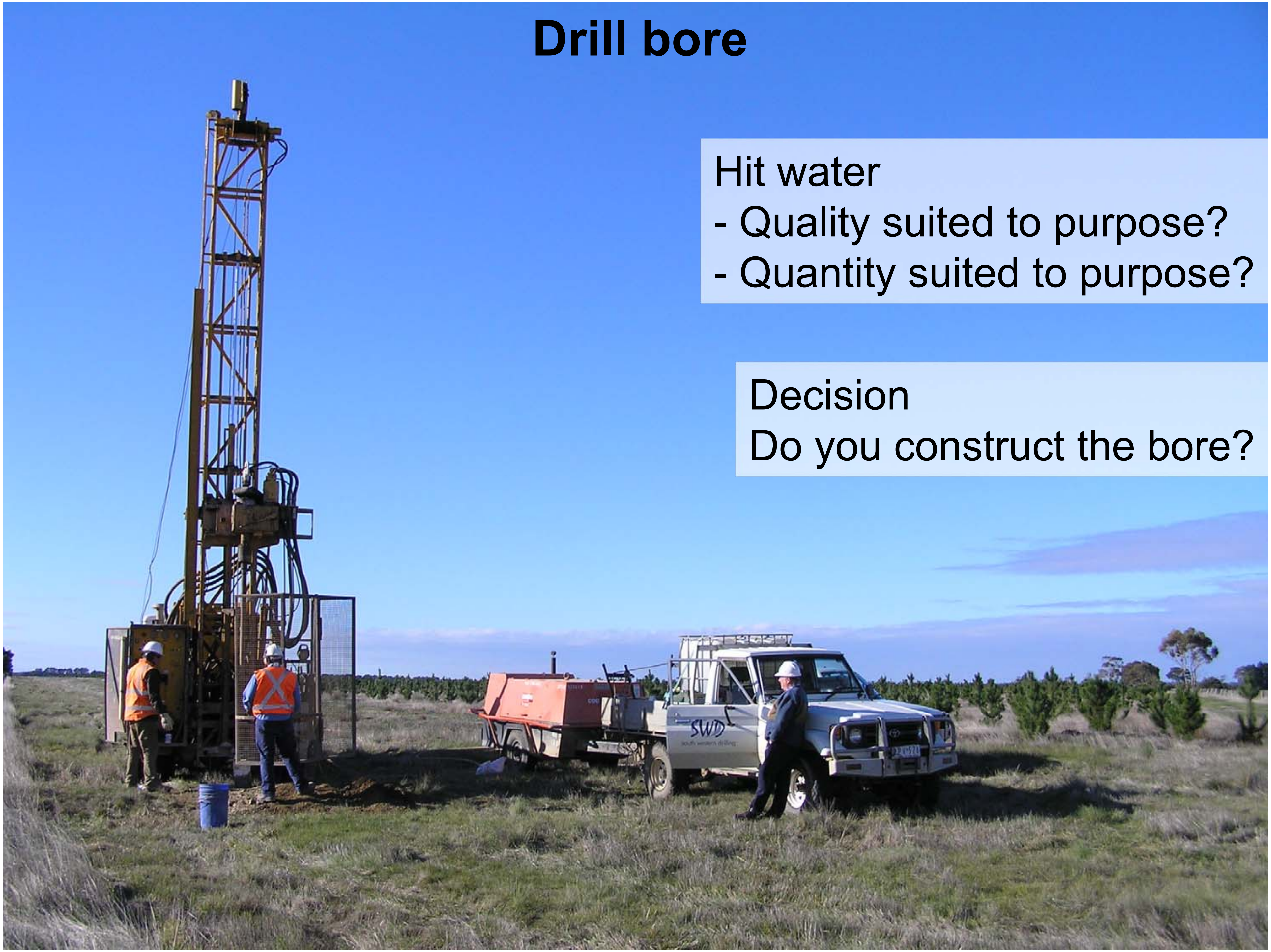
Bores are drilled for many purposes: urban water supplies, geothermal, salinity monitoring, contamination studies, rural water supply, mine dewatering, geotechnical investigations, etc., etc.

Field reconnaissance



- Access for drill rigs
- Infrastructure
- Regulations

Drill bore

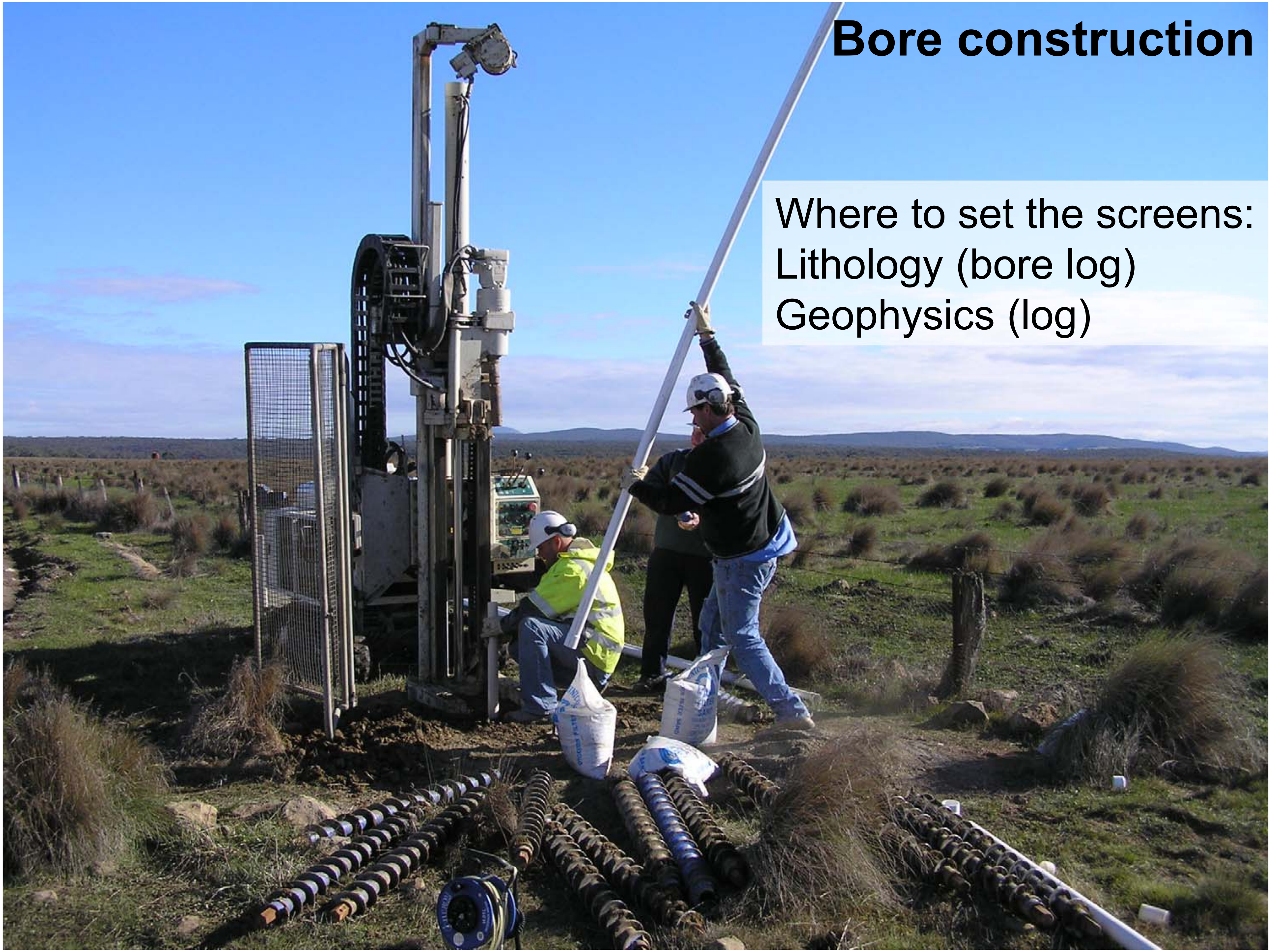


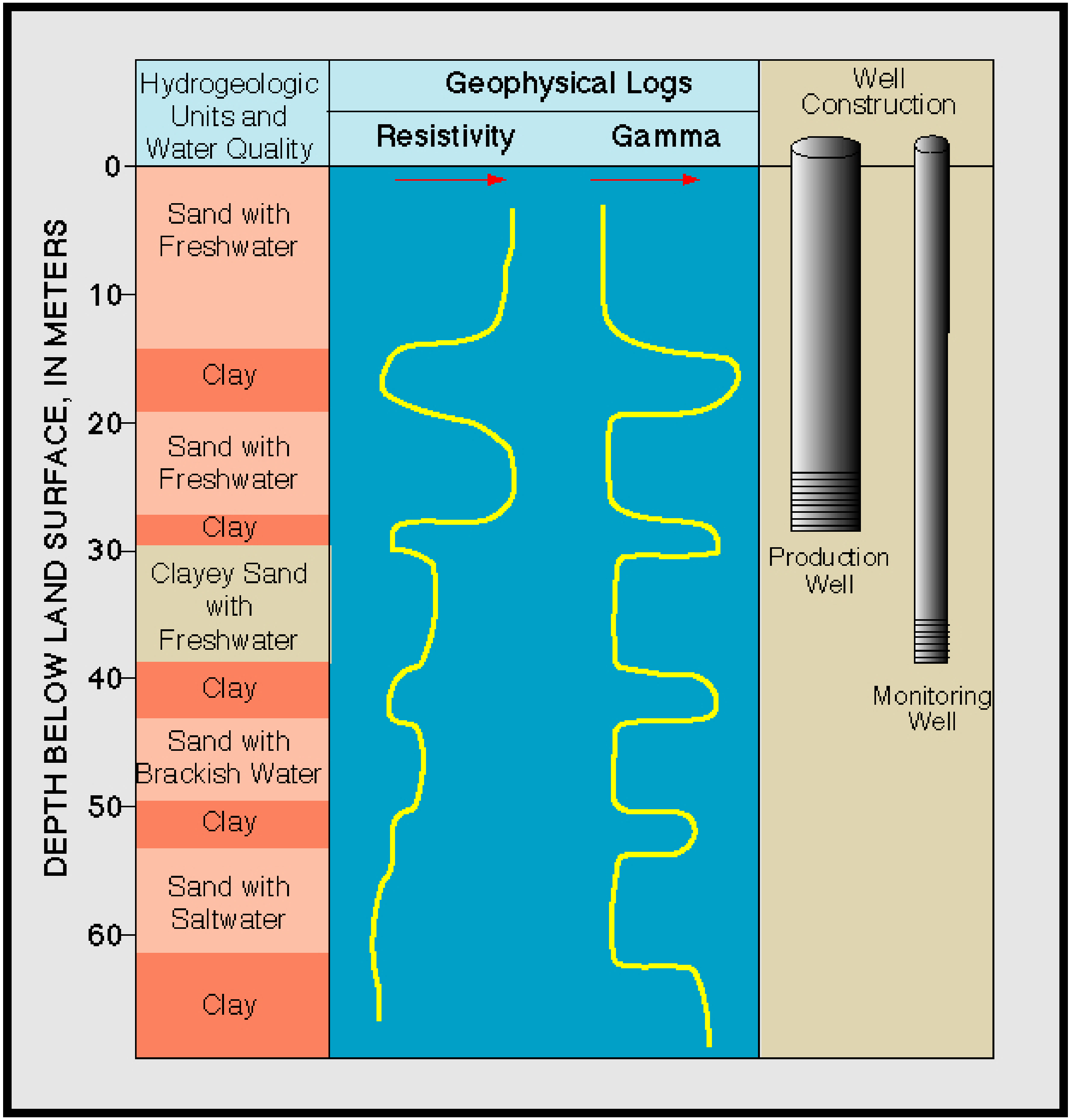
Hit water
- Quality suited to purpose?
- Quantity suited to purpose?

Decision
Do you construct the bore?

Bore construction

Where to set the screens:
Lithology (bore log)
Geophysics (log)



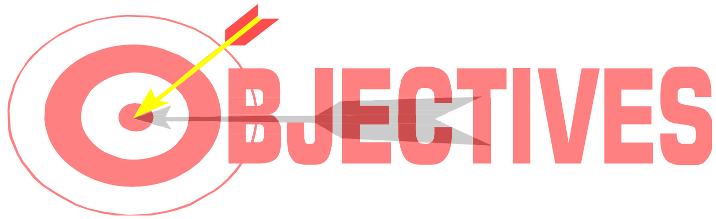


Hydrogeologic Units and Water Quality
Geophysical Logs
Resistivity
Gamma
Well Construction
DEPTH BELOW LAND SURFACE, IN METERS
0
10
20
30
40
50
60
Sand with Freshwater
Clay
Sand with Freshwater
Clay
Clayey Sand with Freshwater
Clay
Sand with Brackish Water
Clay
Sand with Saltwater
Clay
Production Well
Monitoring Well

DRILLED WELLS

- ➔ **Casing material: Steel or PVC plastic**
- ➔ **Installed by well drilling contractors**
- ➔ **Much more common than driven or dug wells**
- ➔ **Most are >50 ft. deep (avg. 125 ft.)**
- ➔ ***MOST SANITARY WELL TYPE***

WATER WELL DESIGN



- ❖ **Provide well that meets needs of owner**
- ❖ **Obtain highest yield with minimal drawdown (consistent w/ aquifer capabilities)**
- ❖ **Provide suitable quality water (potable and turbidity-free for drinking water wells)**
- ❖ **Provide long service life (25+ years)**

NEW: Minimize impacts on neighboring wells & aquatic environments

WATER WELL DRILLING METHODS

MOST COMMON:

ROTARY
(Mud & Air)

84%

LESS COMMON:

CABLE TOOL
10%

AUGER
2.5%

JETTING
1%

HOLLOW ROD
0.5%

OTHER
2%

EMERGING TECHNOLOGY

DUAL TUBE ROTARY

HORIZONTAL

SONIC


Rotary


Cable Tool

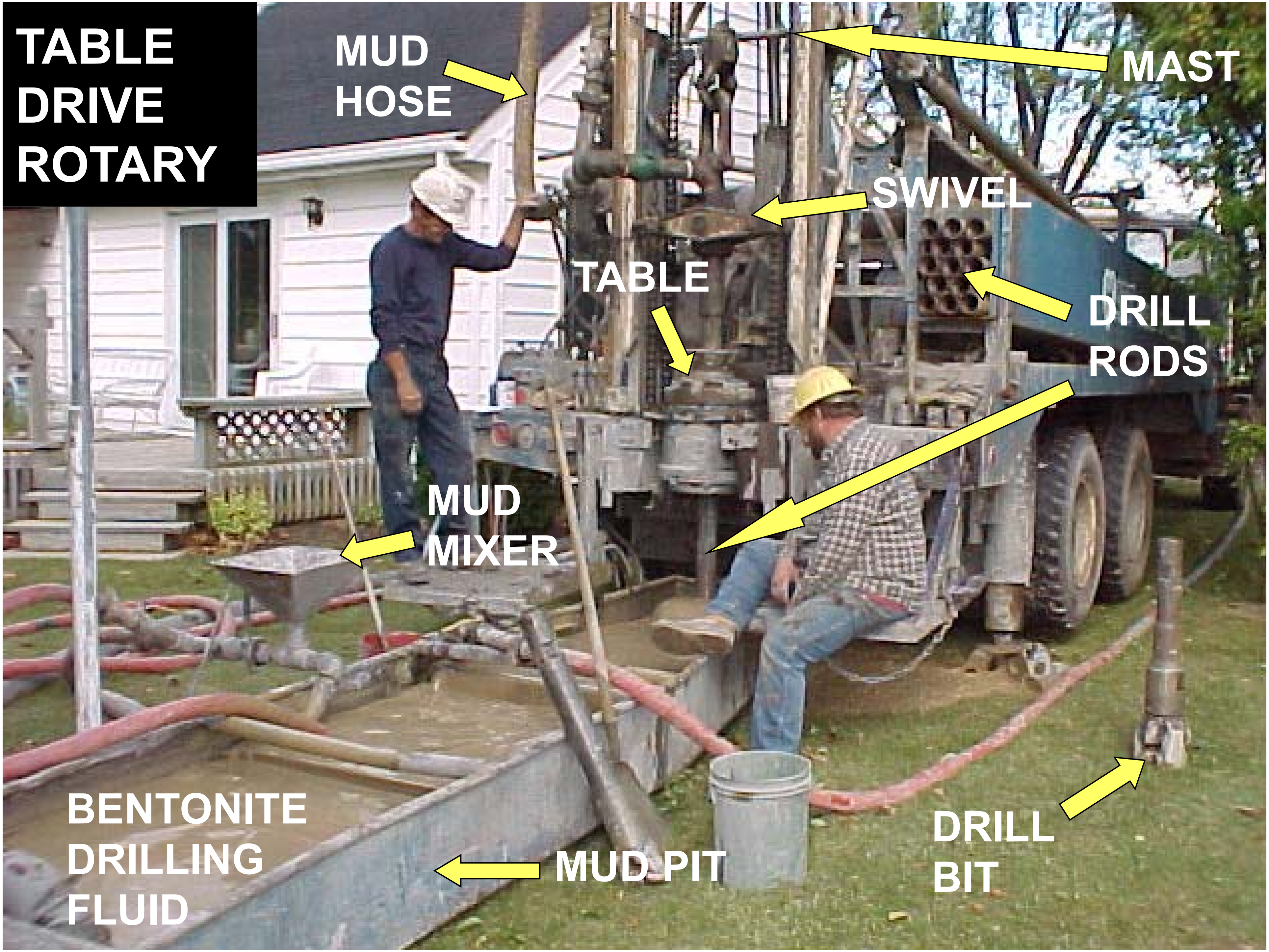


TABLE DRIVE ROTARY
MUD HOSE
MAST
SWIVEL
TABLE
DRILL RODS
MUD MIXER
BENTONITE DRILLING FLUID
MUD PIT
DRILL BIT

TOP HEAD DRIVE ROTARY

DRILLING RIG OPERATOR CHECKING DRILL CUTTINGS

STRAINER

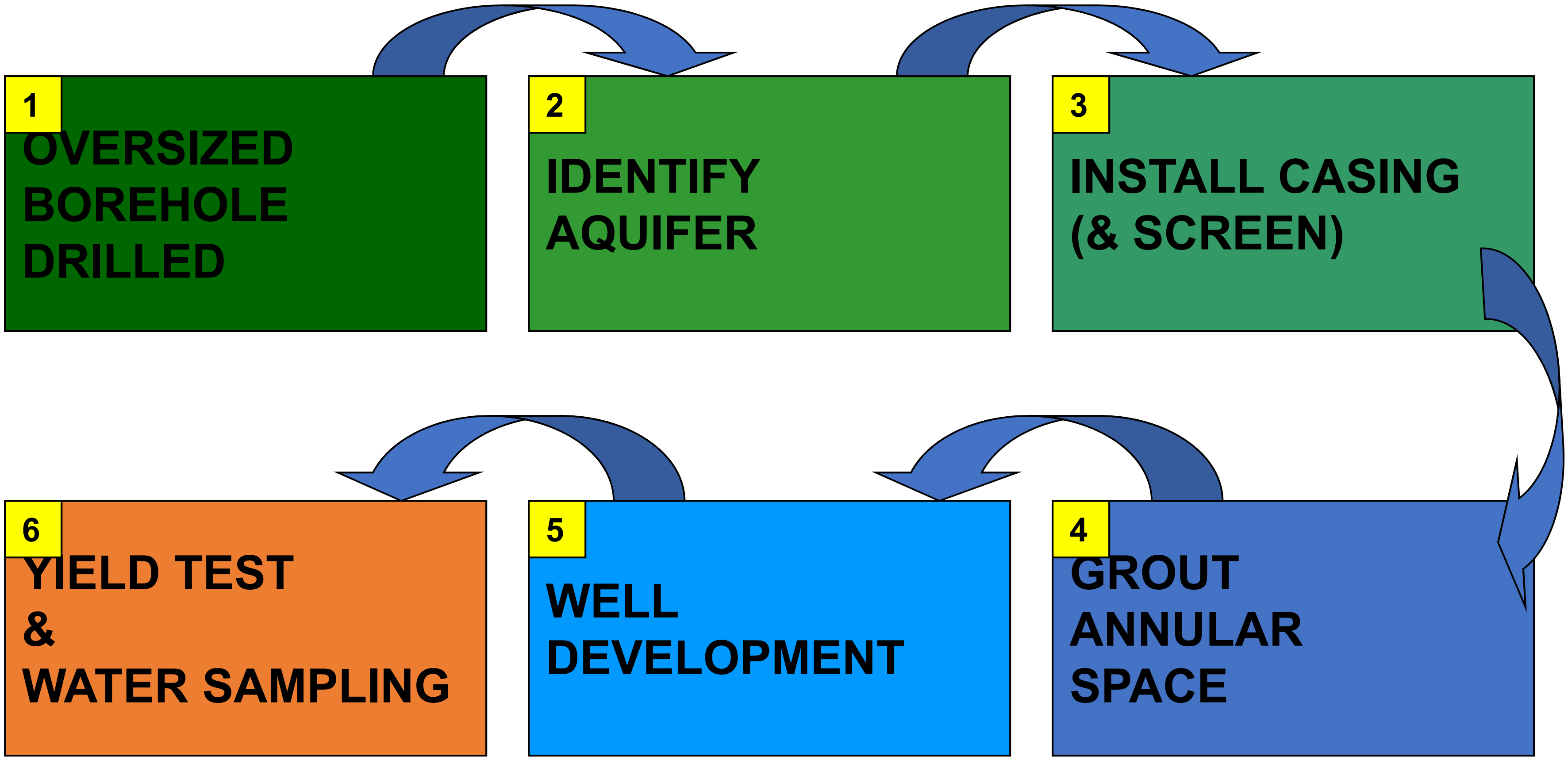
DRILLING FLUID EXITING BOREHOLE

DRILLER COMPLETING THE WATER WELL RECORD

WATER WELL & PUMP RECORD DESCRIBES:

WELL DEPTH
CASING LENGTH
GEOLOGIC MATERIALS PENETRATED
STATIC WATER LEVEL
PUMPING WATER LEVEL
PUMPING RATE
GROUTING MATERIALS
WELL LOCATION
PUMPING EQUIPMENT
DRILLERS NAME
DRILLING RIG OPERATOR

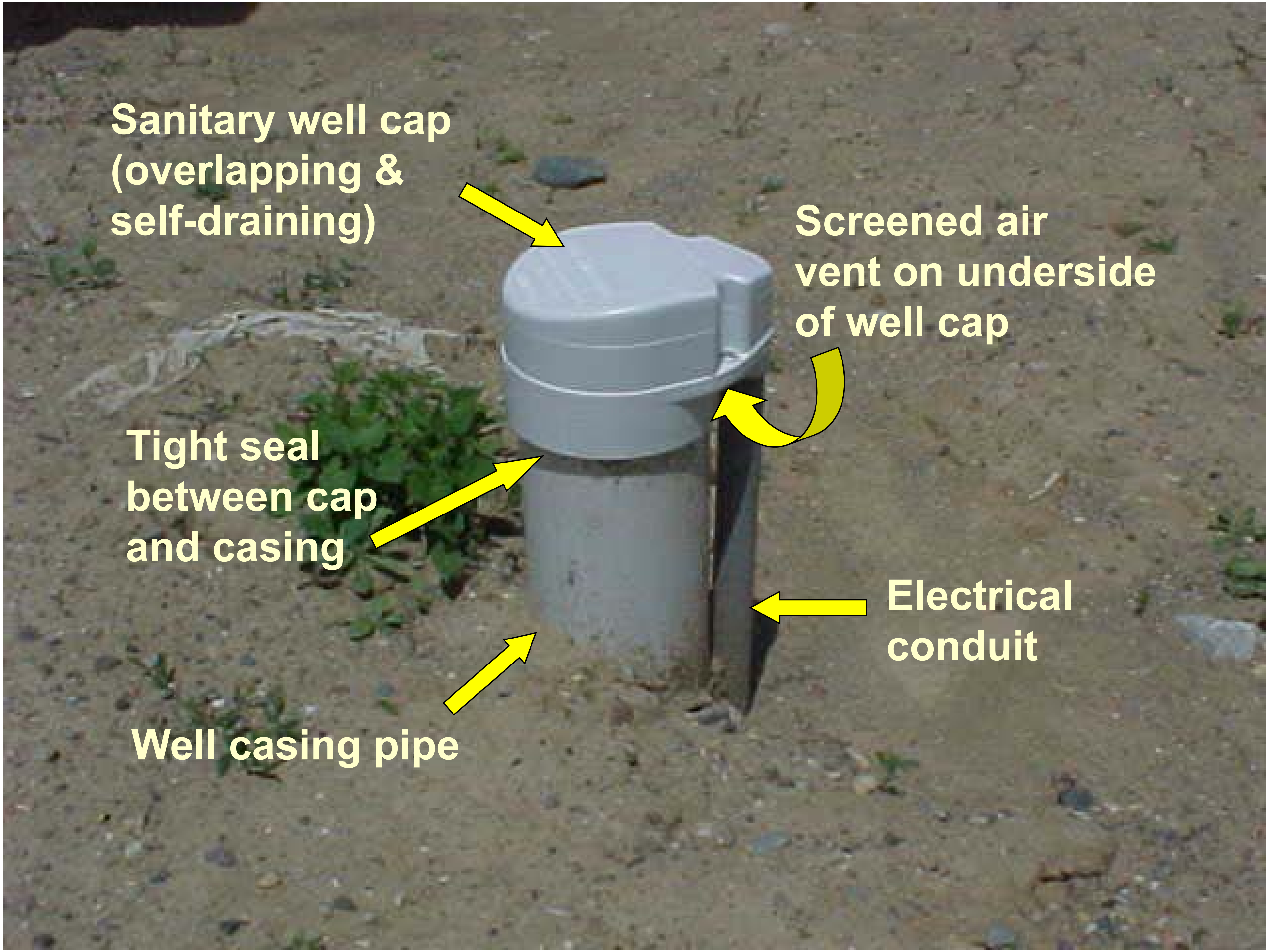
TYPICAL
ROTARY WELL CONSTRUCTION
SEQUENCE



Bentonite Drilling Fluid
- *Functions* -

- REMOVAL OF DRILL CUTTINGS FROM BOREHOLE
- STABILIZE THE BOREHOLE
- COOL AND LUBRICATE DRILL BIT
- CONTROL FLUID LOSS TO GEOLOGIC FORMATIONS
- DROP DRILL CUTTINGS INTO MUD PIT
- FACILITATE COLLECTION OF GEOLOGIC DATA
- SUSPEND CUTTINGS WHEN DRILLING FLUID CIRCULATION STOPS

Temporary well cap - installed between well drilling and pump hook-up


Sanitary well cap (overlapping & self-draining)
Screened air vent on underside of well cap
Tight seal between cap and casing
Electrical conduit
Well casing pipe

This drilled well has an older style well cap that does not seal tightly to the well casing.

Insects and small animals can enter the well and contaminate the drinking water.

Caps of this design are not acceptable and should be replaced.

DRILLED WELL COMPONENTS

WELL CAP or SEAL

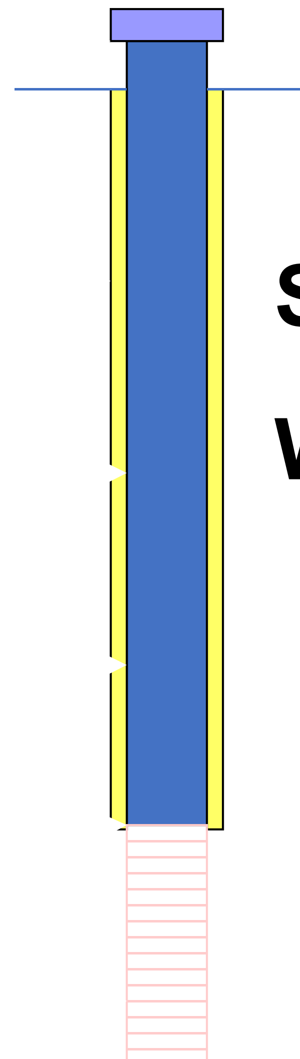
BOREHOLE

CASING

GROUT

PACKER

SCREEN



SCREENED WELL

DRILLED WELL COMPONENTS

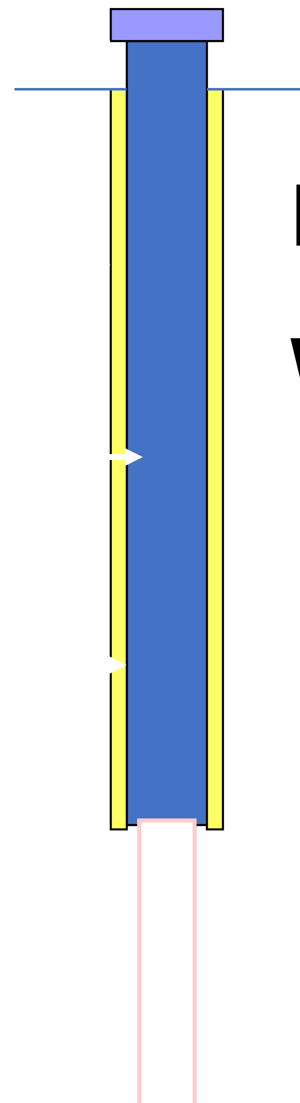
WELL CAP

BOREHOLE

CASING

GROUT

OPEN HOLE IN BEDROCK AQUIFER



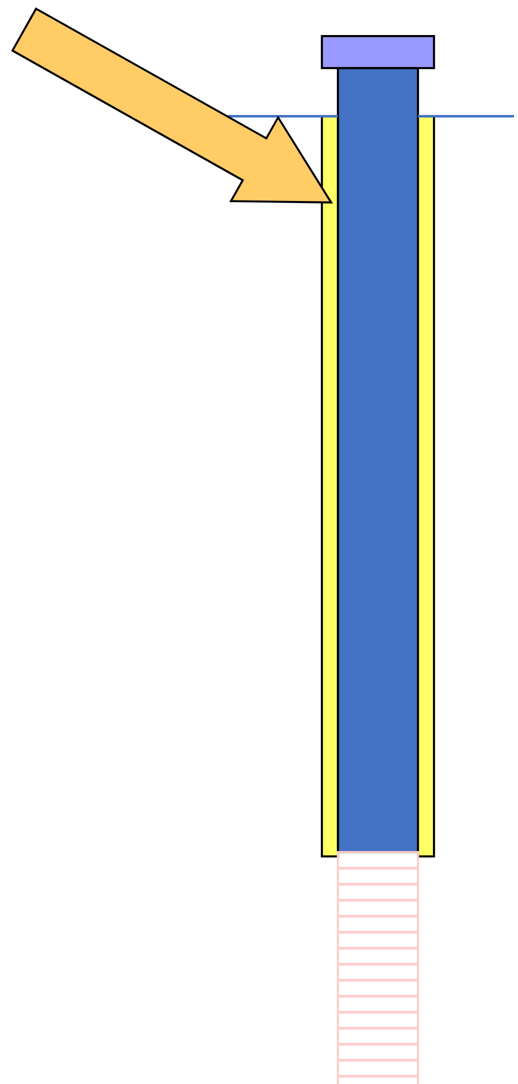
BEDROCK

WELL

NO CASING IN ROCK BOREHOLE

BOREHOLE

Vertical circular boring to reach aquifer (water bearing geologic material)



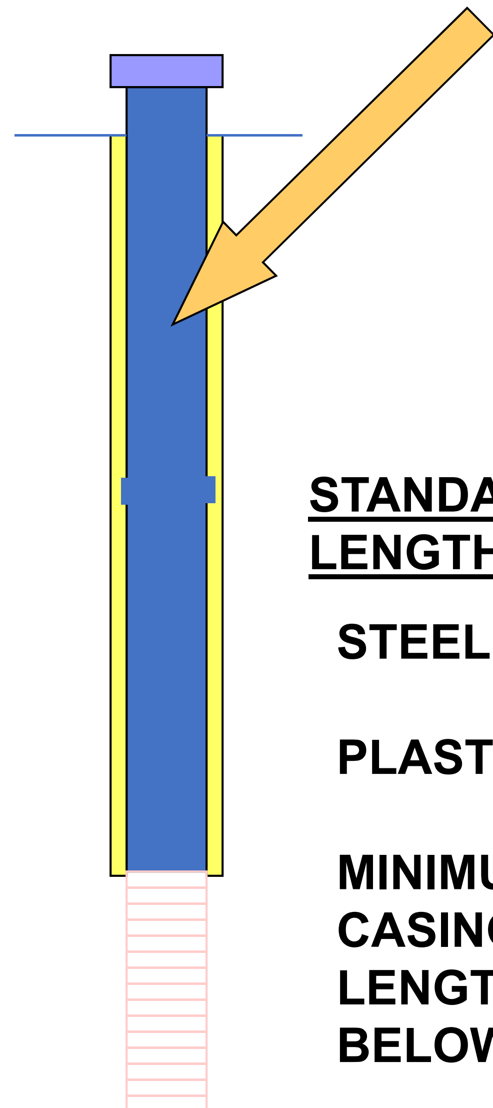
MINIMUM 2 IN. LARGER THAN CASING IF GROUTING THRU CASING

MINIMUM 2 7/8 IN. LARGER THAN CASING IF GROUTING WITH GROUT PIPE OUTSIDE CASING

CASING

Steel or plastic pipe installed to keep borehole wall from collapsing

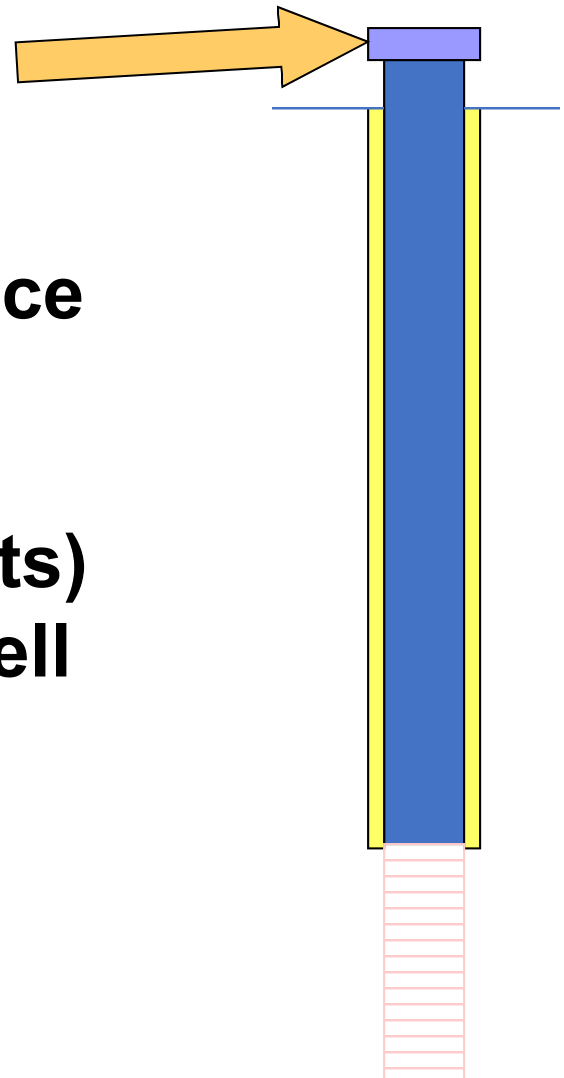
Houses submersible pump or turbine bowls & drop pipe



<u>STANDARD LENGTHS</u>

STEEL	21 FT.
PLASTIC	20 FT.
MINIMUM CASING LENGTH BELOW GRADE	25 FT.

WELL CAP or SEAL



Mechanical device to prevent contaminants (including insects) from entering well casing

OVERLAPPING

SEALED TIGHTLY TO CASING

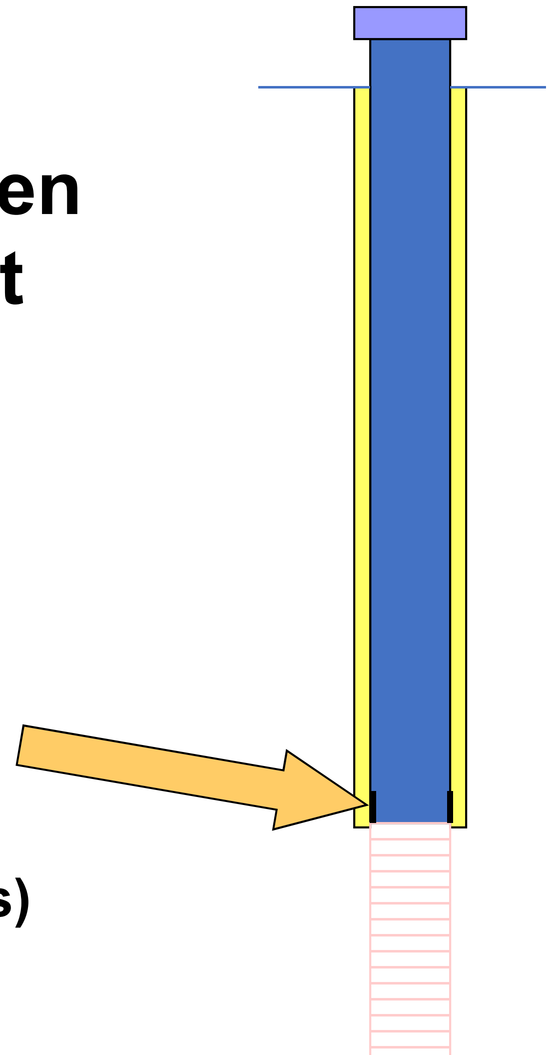
SCREENED AIR VENT

TIGHT SEAL TO ELECTRICAL CONDUIT

Device that seals space between casing & telescoped screen to keep sand out of well

PACKER

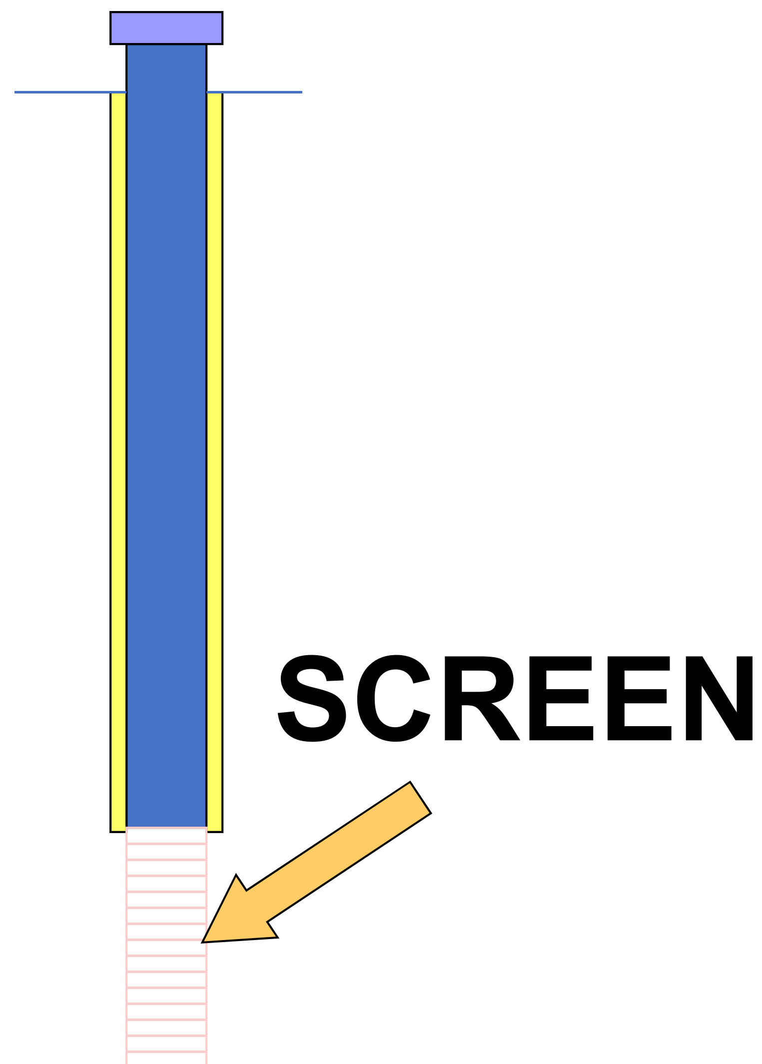
(Coupling with neoprene rubber flanges)

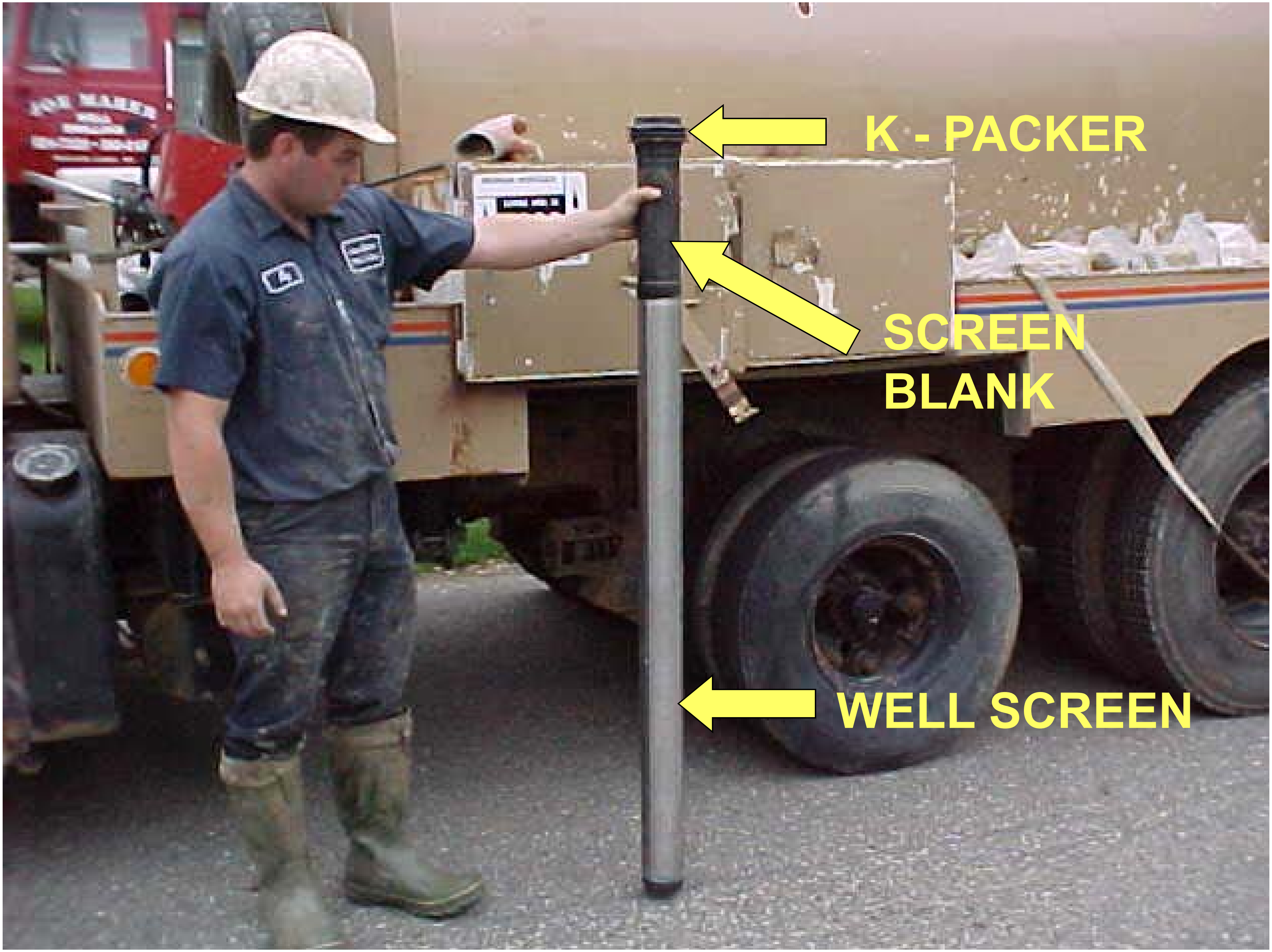


Intake device to allow water to enter well and keep sand out

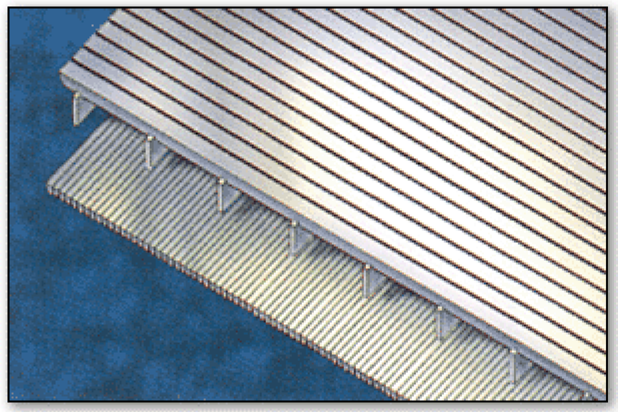
Structural support of aquifer material

Wire-wrapped screen most common




K - PACKER
SCREEN
BLANK
WELL SCREEN

Wound Wire Screens



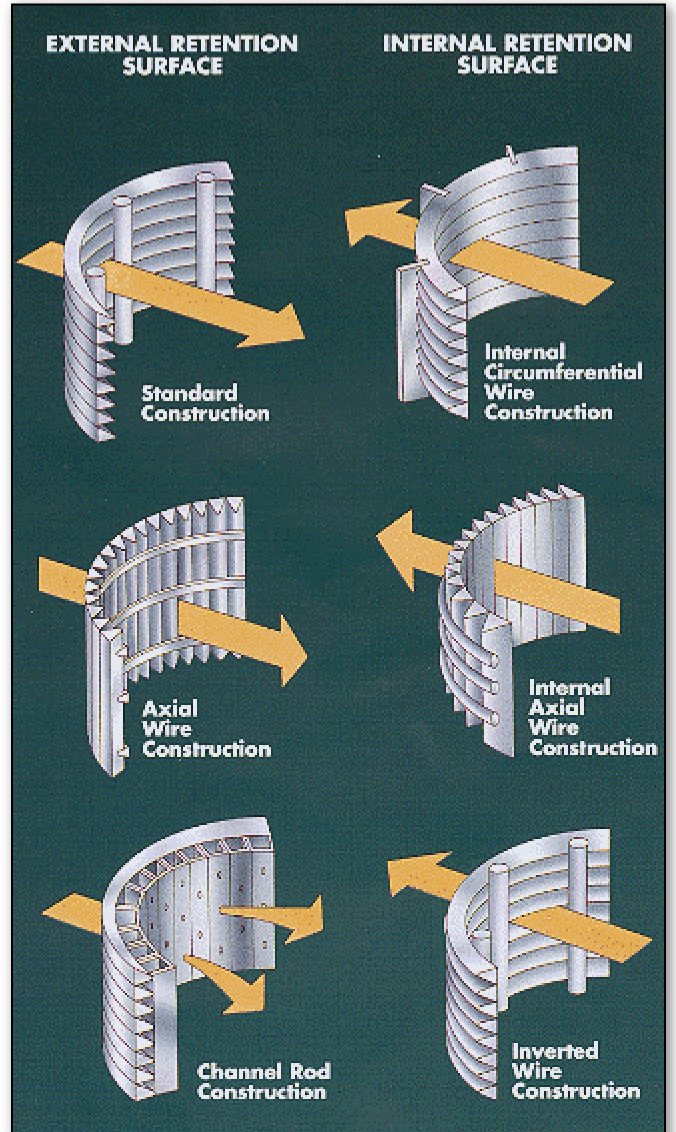


Table 9.1 Reactivity of Steel Casing to Corrosive Waters

Reactive Agent	Water Quality	Reaction
pH	less than 5.5	corrosive
O_2	more than 4 mg/L	corrosive
CO_2	more than 100 mg/L	corrosive
CO_2	50 to 100 mg/L	marginal/corrosive
CO_2	less than 50 mg/L	acceptable

Sintered HDPE Screens

PVC Screens

Table 9.2 Comparison of Strengths of Bore Casing Materials

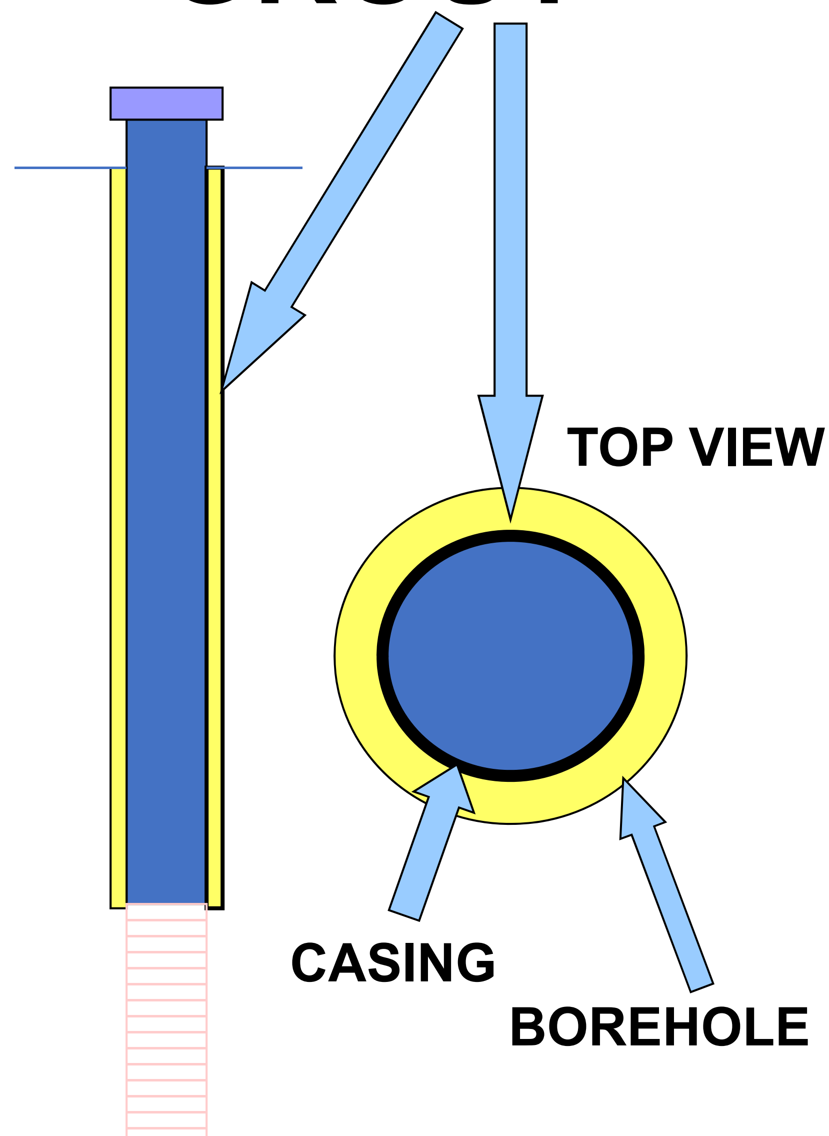
Material	Specific Gravity	Tensile Strength 10^3 kPa	Tensile Modulus 10^5 kPa	Impact Strength (3)	Upper Temp. Limits, °C
ABS	1.04	31	20.0	6.0	50
PVC	1.40	55	28.0	1.0	40
Fibreglass	1.89	115	158.0	20.0	80
FRP					(4)
Steel	7.85	240 (yield) 410 (ultimate)	2 068.0	(2)	800 - 1000
Stainless Steel	8.0	240 (yield) 550 (ultimate)	2 000.0	(2)	800 - 1000

(1) Yield strength is the tensile stress required to produce a total elongation of 0.5 percent of the gauge length as determined by an extensiometer. Expressed in psi.
(2) The impact strength of steel is so high relative to the demands of water well work that it can be ignored in design considerations.
(3) Relative to PVC.
(4) FRP higher temperature with special resins.

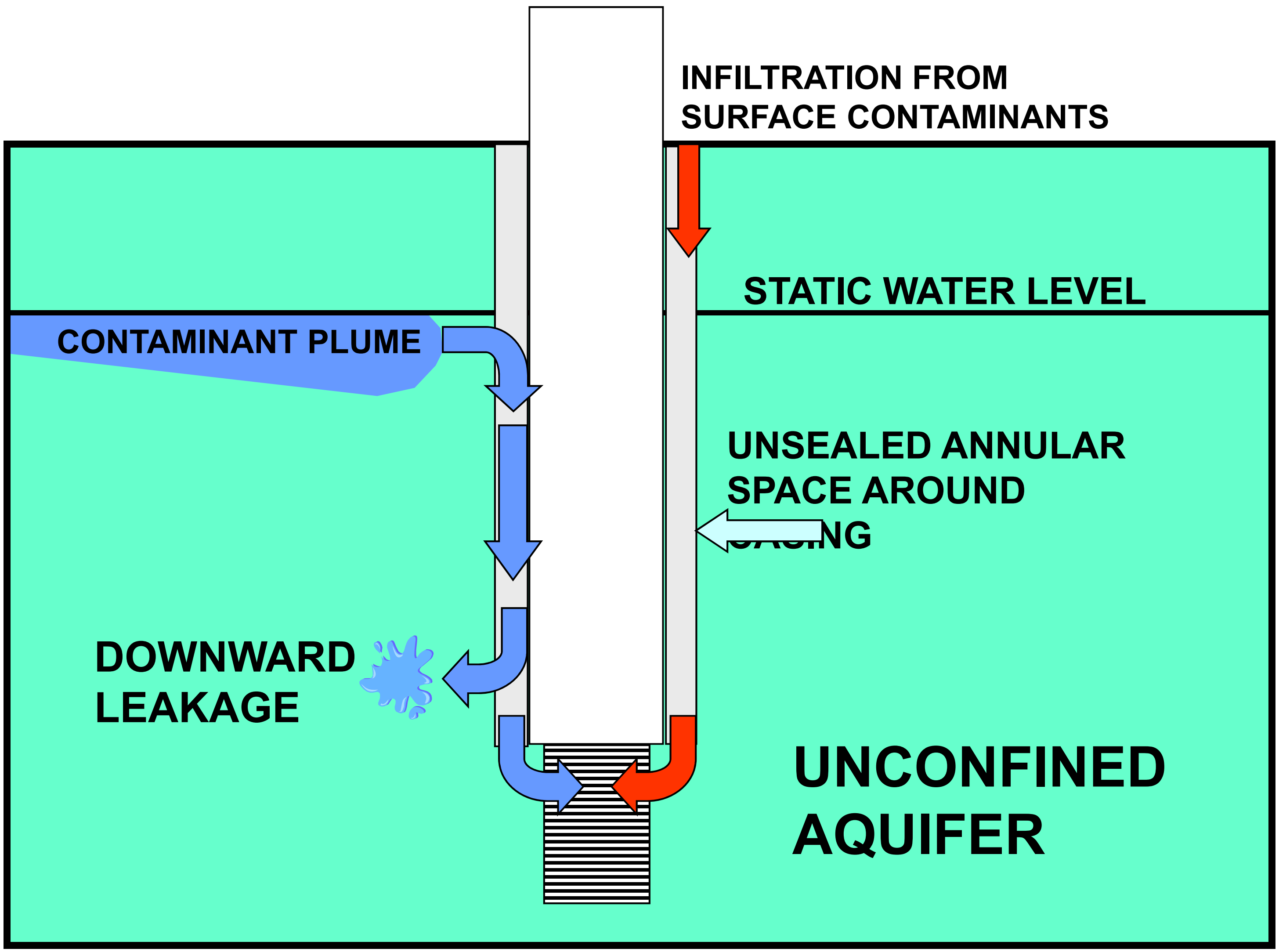
GROUT

Impermeable cement or bentonite clay slurry placed in annular space between borehole and casing to:

- **prevent well contamination**
- **maintain separation of aquifers**
- **preserve artesian aquifers**

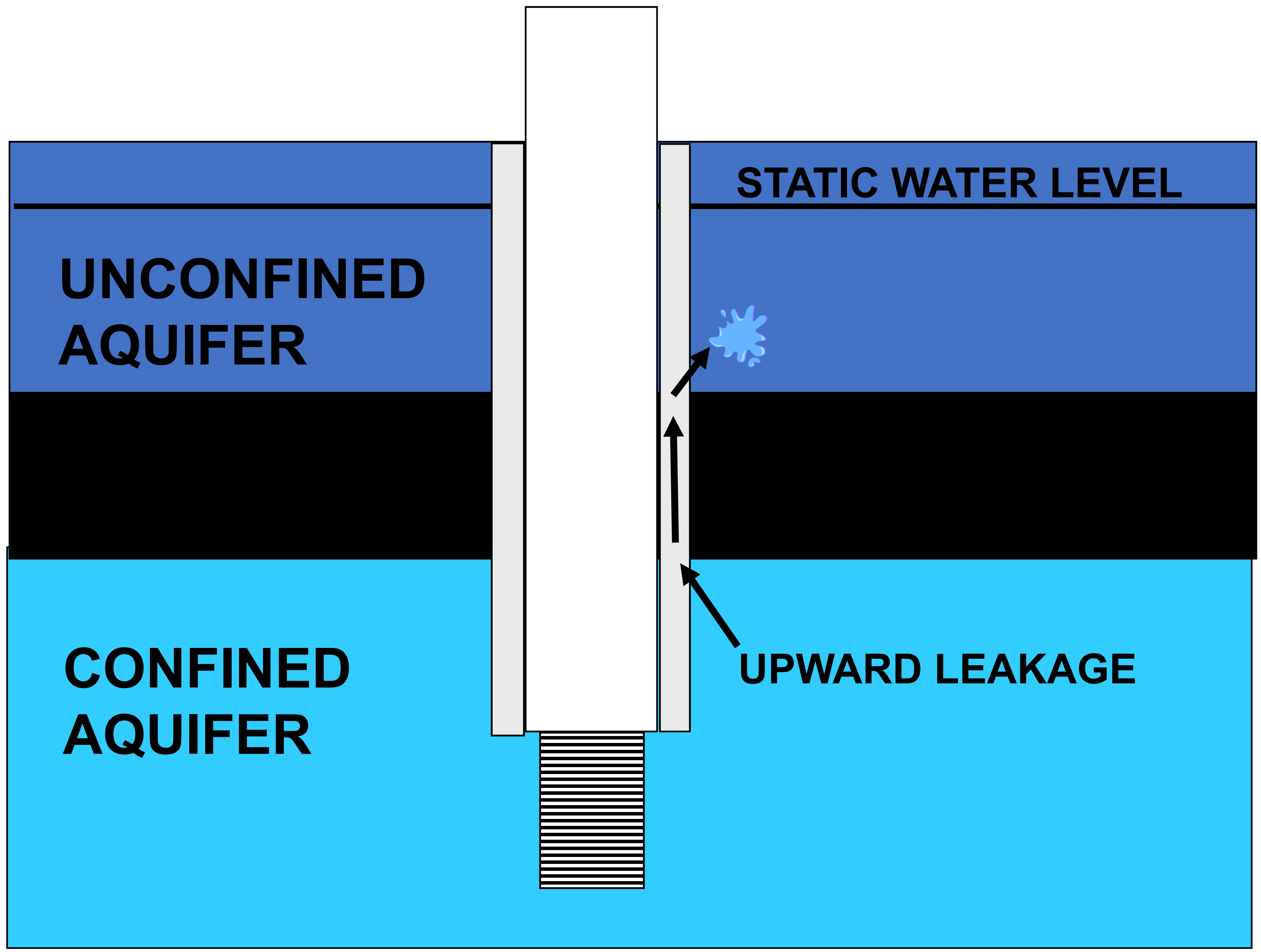


DOWNWARD LEAKAGE AROUND UNGROUTED CASING



UPWARD LEAKAGE AROUND UNGROUTED CASING

(Artesian Condition)



BENEFITS OF WELL GROUTING

- *PREVENT CONTAMINANT MIGRATION FROM SURFACE (Keeps surface runoff from moving downward along well casing)*
- *SEAL OFF POOR QUALITY AQUIFERS*

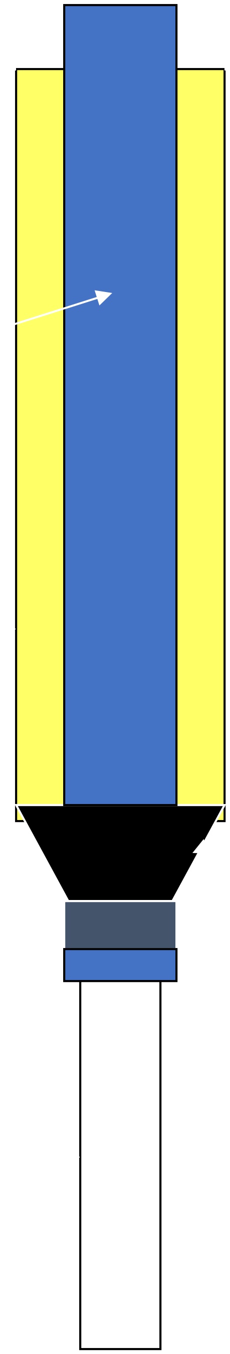
  (Prevents mixing of water from different aquifers)
- *PRESERVE ARTESIAN AQUIFER PROPERTIES*
- *ADDED SEALING OF CASING JOINTS*

BEDROCK WELL DETAILS

CASING PIPE

GROUT

TOP OF BEDROCK

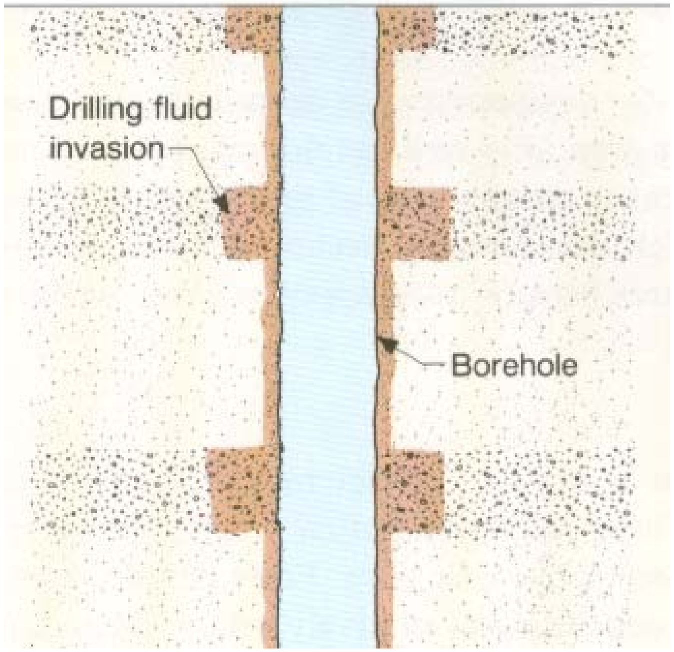


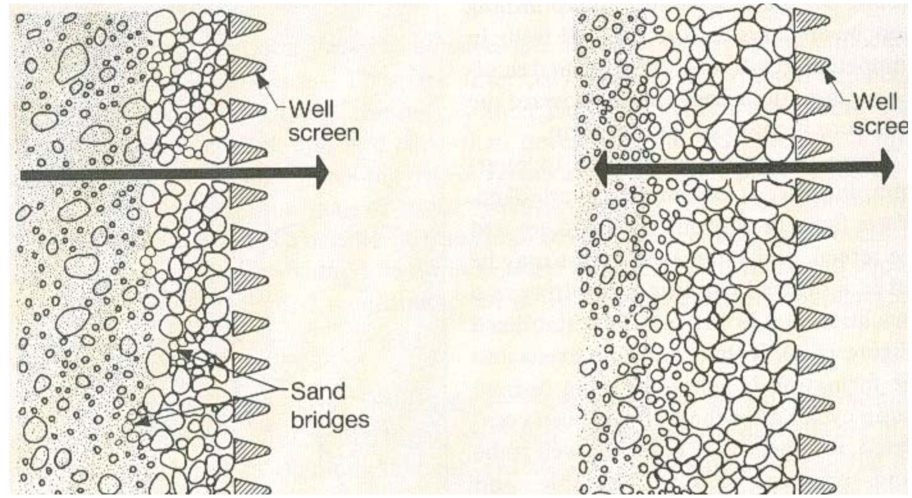
SHALE TRAP
OR
SHALE PACKER

PREVENTS GROUT SPILLAGE INTO BEDROCK BOREHOLE

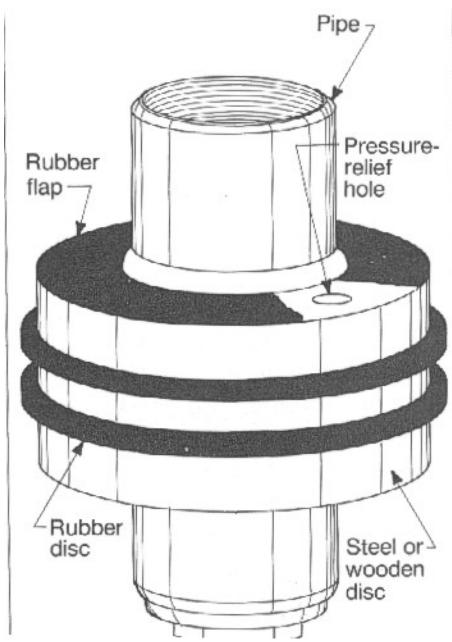
BETTER SEAL AT BEDROCK INTERFACE

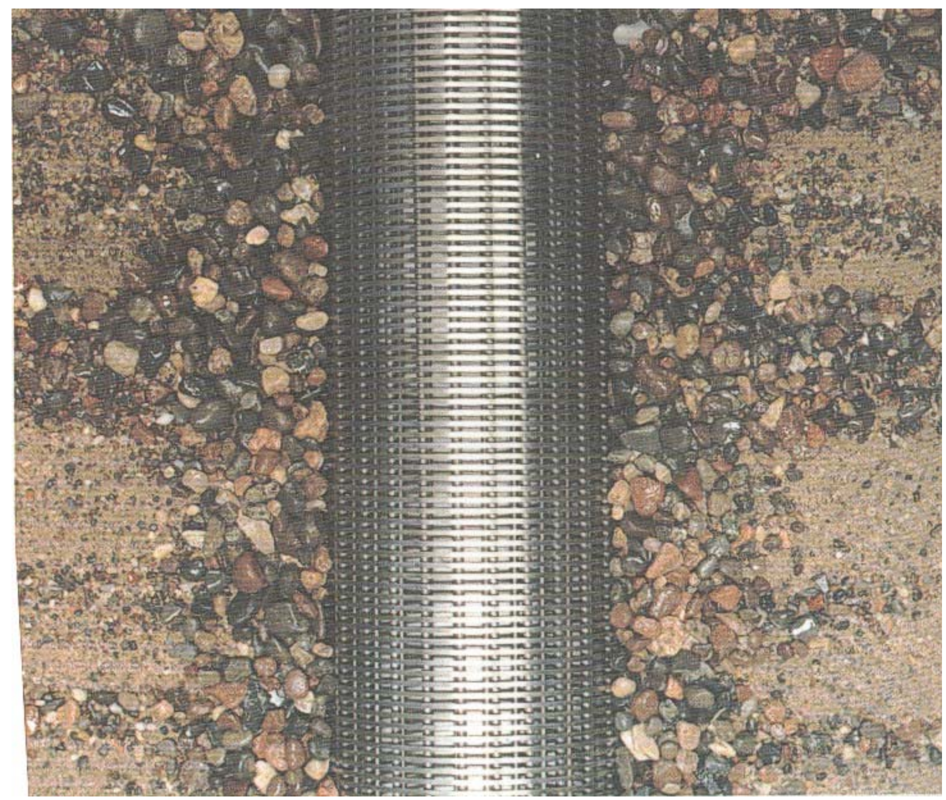
BEDROCK BOREHOLE (SMALLER DIAMETER THAN CASING)





Bore Development





Electric submersible pumps

DUG WELLS

- Large diameter (18-48 in.)
- Found in low yield areas
- Casing material - concrete crocks w/ loose joints

  Older wells: stones, brick-lined
- Water enters well through loose casing joints


SHALLOW UNSANITARY DUG CROCK WELL


OLD UNSANITARY HAND-DUG WELL
LINED WITH FIELD STONE

DUG WELLS

- Older wells - hand dug
- Now installed (on very limited basis) w/ bucket augers (backhoes – phased out)
- Low well yield - storage in casing (100’s of gallons)
- HIGHLY VULNERABLE TO CONTAMINATION

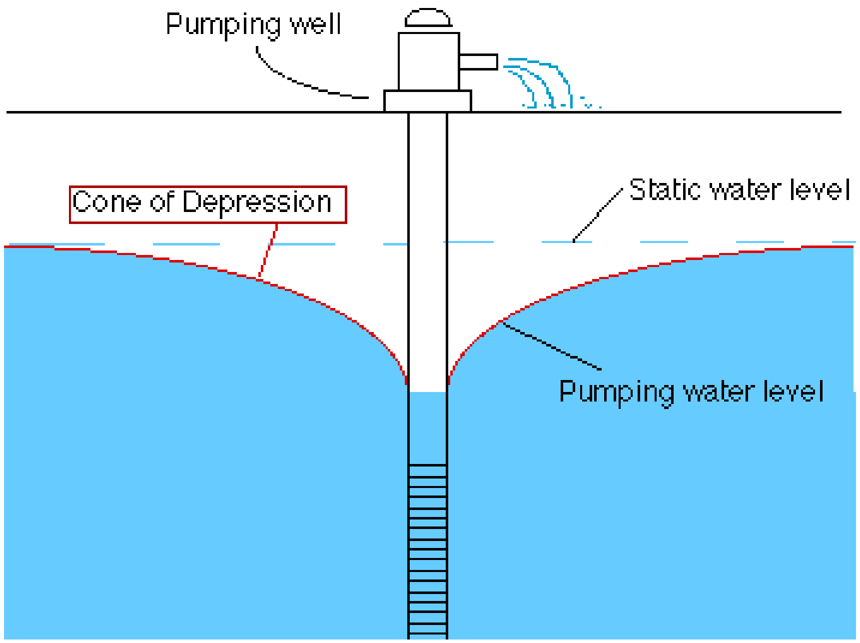
CDC Findings on Dug Wells

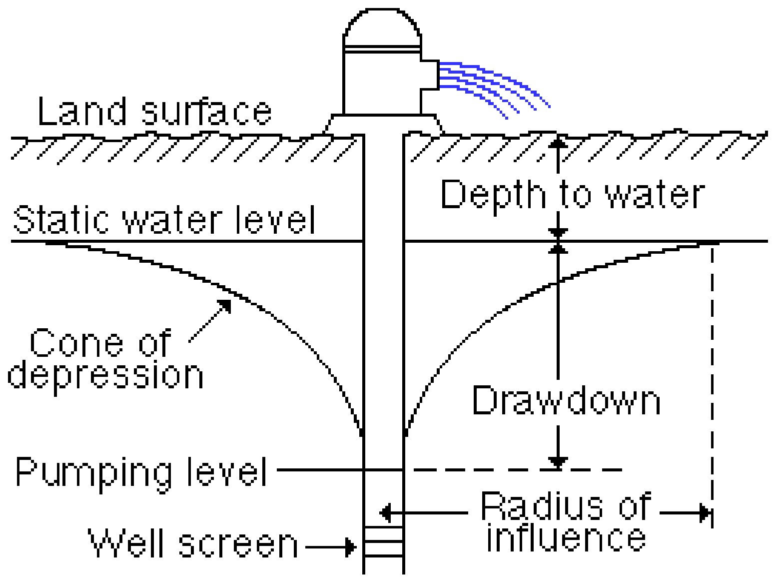
- **Dug/bored wells had a positive coliform bacteria rate of about 85%**

- **Wells with brick, concrete or wood casing (dug wells) had coliform positive rates of 60 – 90 %**

From *A Survey of the Presence of Contaminants in Water From Private Wells in Nine Midwestern States*, Atlanta, Georgia, U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, 1996

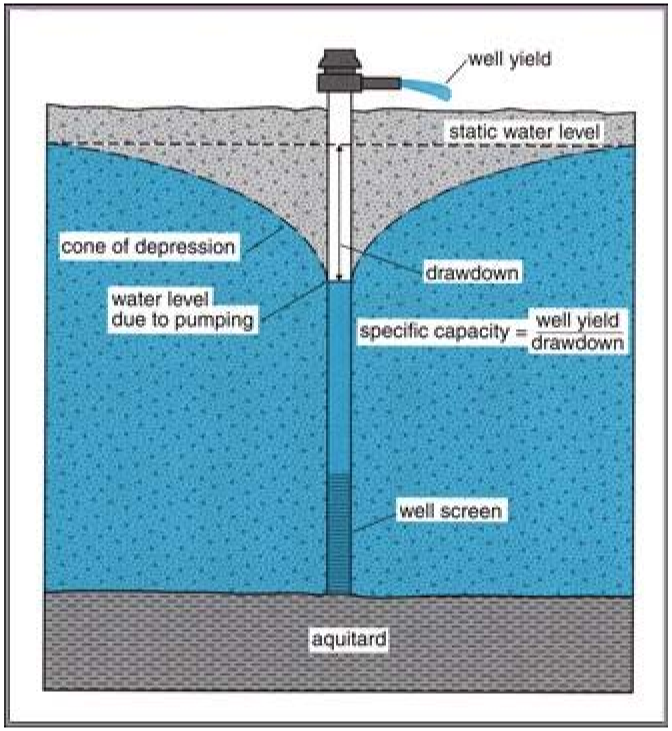

Photograph (C) 1995 by Gregg A. Eckhardt

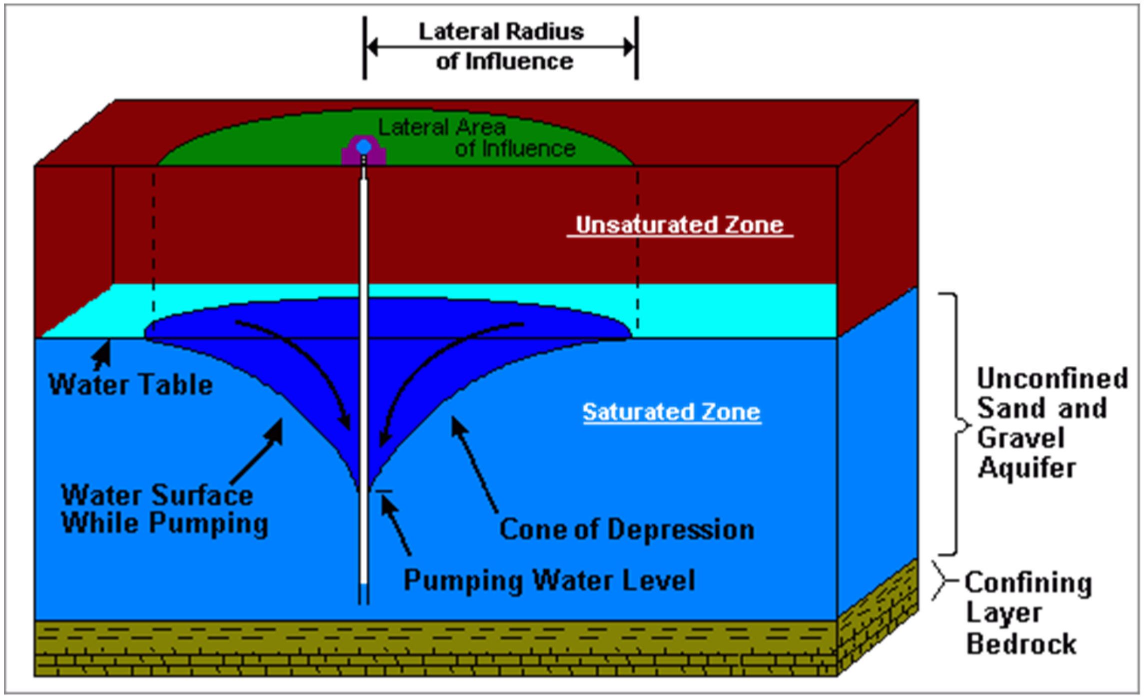




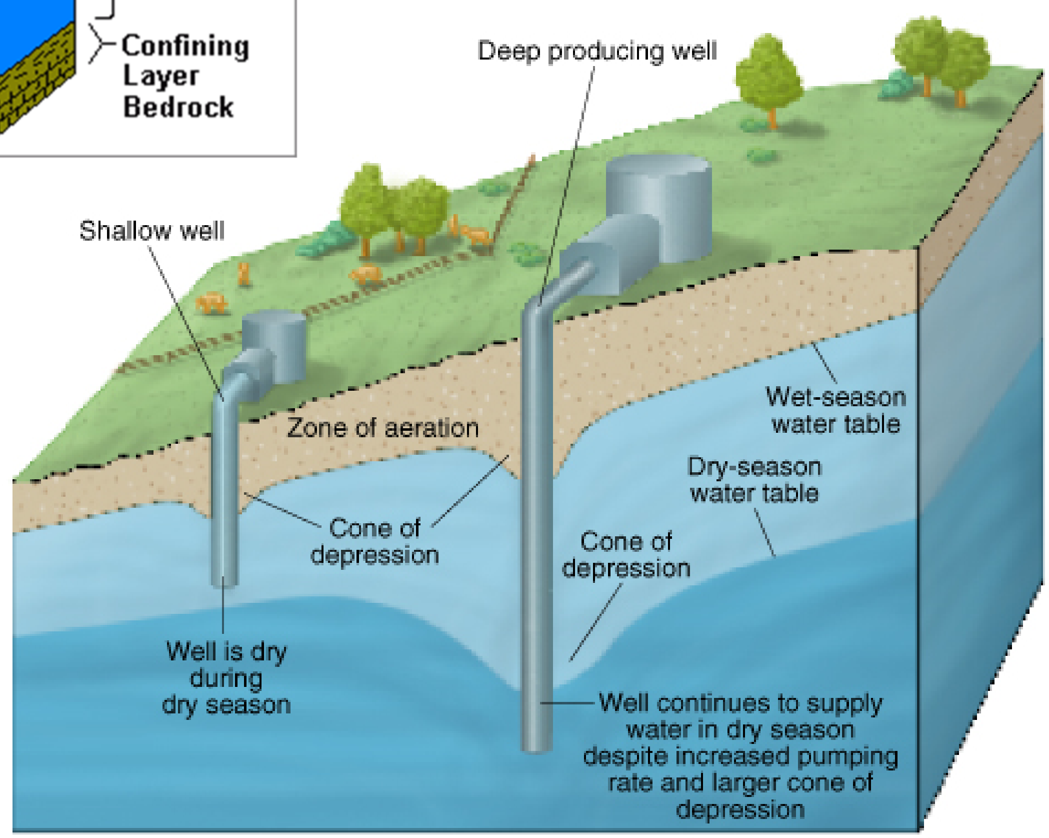
Some useful terms to know:

- ✓ Cone of depression
- ✓ Drawdown
- ✓ Radius of influence
- ✓ Specific capacity



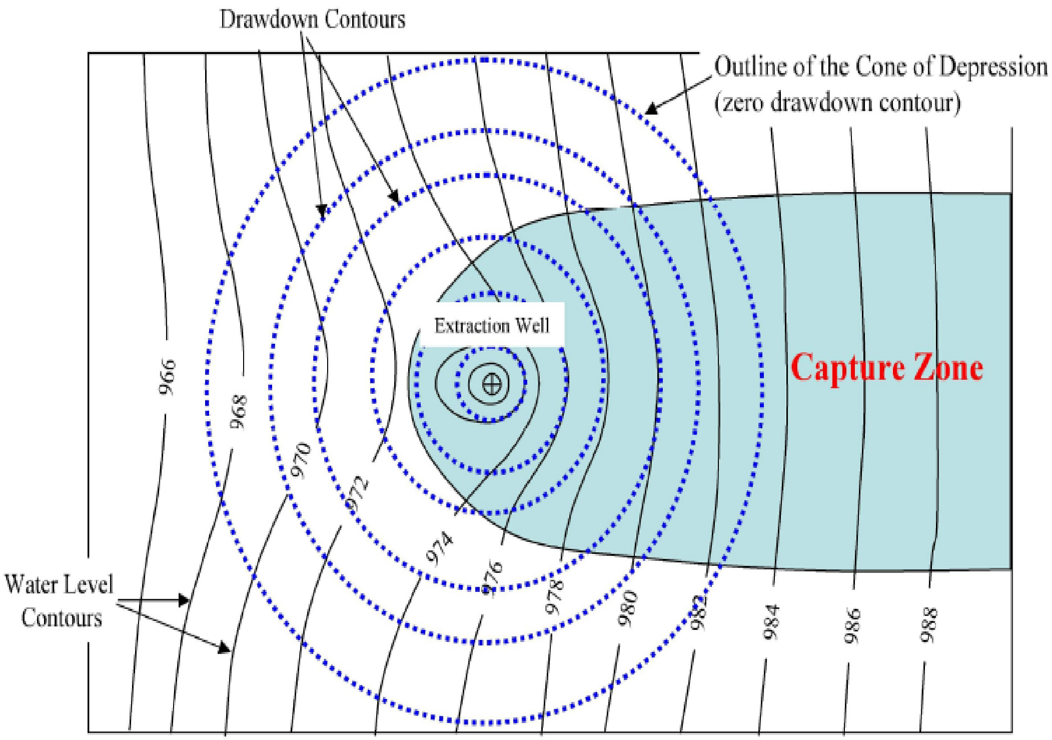


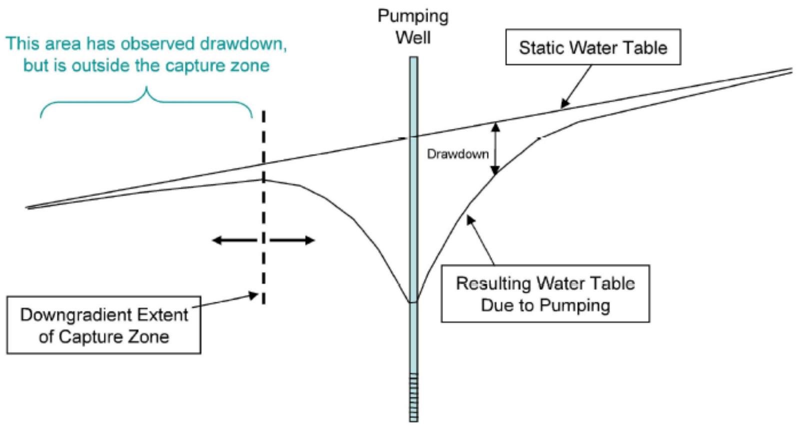
Lateral Radius of Influence
Lateral Area of Influence
Unsaturated Zone
Water Table
Saturated Zone
Unconfined Sand and Gravel Aquifer
Water Surface While Pumping
Cone of Depression
Pumping Water Level
Confining Layer Bedrock



Deep producing well
Shallow well
Zone of aeration
Wet-season water table
Dry-season water table
Cone of depression
Cone of depression
Well is dry during dry season
Well continues to supply water in dry season despite increased pumping rate and larger cone of depression

Capture Zone vs. Drawdone Cone





Zone 2 Groundwater Protection Area

- **Zone II:** That area of an aquifer which contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated (180 days of pumping at approved yield, with no recharge from precipitation). It is bounded by the **groundwater divides which result from pumping the well and by the contact of the aquifer with less permeable materials such as till or bedrock**. In some cases, streams or lakes may act as recharge boundaries. In all cases, Zone II shall extend upgradient to its point of intersection with prevailing hydrogeologic boundaries (a groundwater flow divide, a contact with till or bedrock, or a recharge boundary).

SAFE YIELD

Two Factors Govern Groundwater Supply Capacity

Well Yield - the maximum rate at which a well can be pumped without causing water levels to be drawn below the level of the pump and uppermost water-bearing zone.

Sustainable Aquifer Capacity - the maximum rate at which the aquifer can transmit water to the well sustainably with long-term pumping.

Factors Influencing Safe Yield

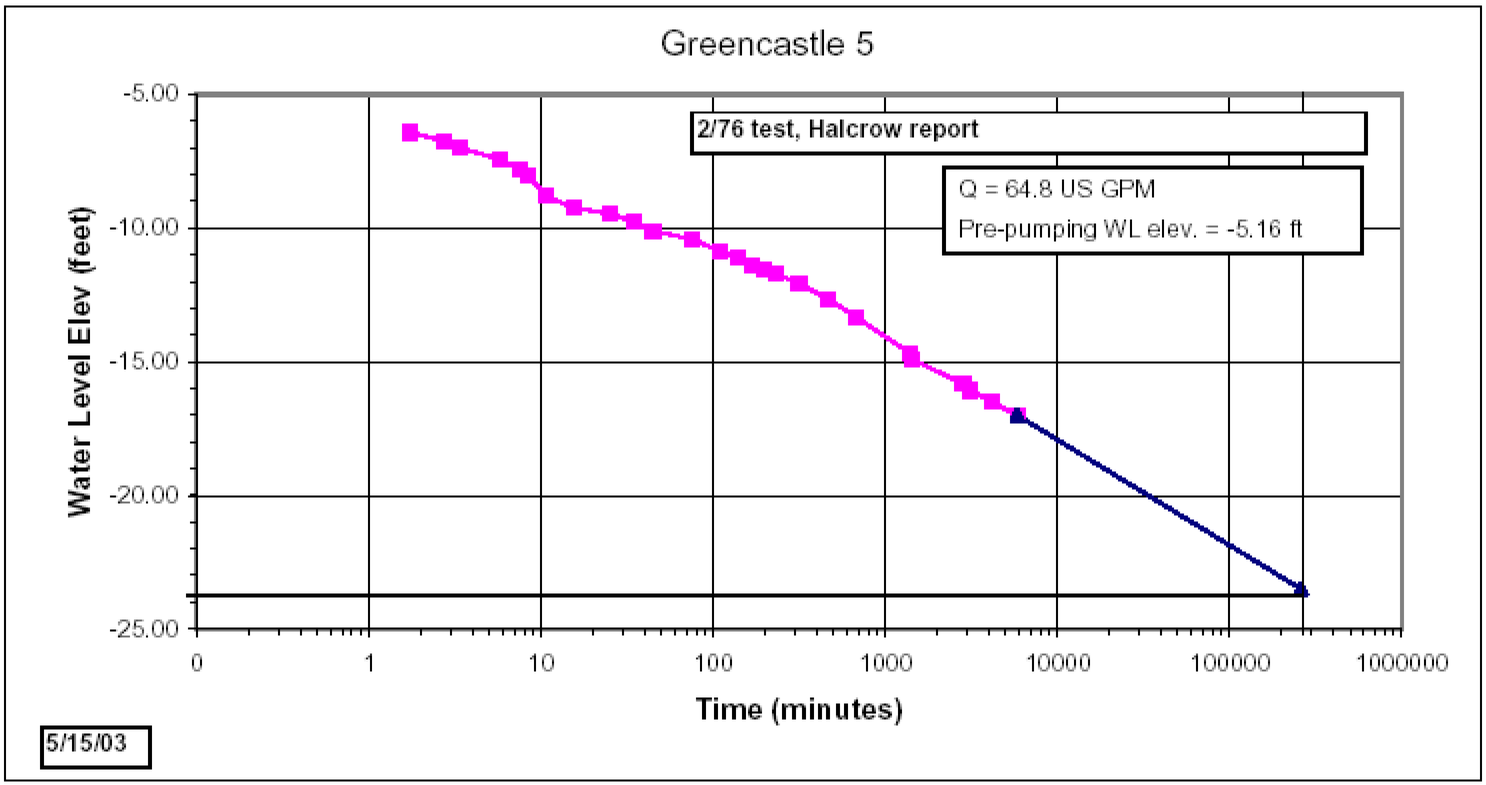
Average Annual Precipitation

- **Watershed Area**
- **Recharge Rate**
- **Presence of Surface Water Bodies**
- **Aquifer Parameters (transmissivity, storativity)**
- **Competing Water Demands**

Knowledge of these variables, combined with a well-formulated conceptual model, can support an initial estimate of likely **Safe Yield** of a well.

180-DAY PROJECTION OF WATER LEVEL TREND

End-of-Test Drawdown trend projected to a period of 180 days (259,200 minutes). Projected water level is 23.5 feet below sea level, assuming no boundaries. Top of water-bearing zone in this gravel-pack well is around 10 feet below sea level, so we would expect trend to steepen as aquifer is gradually dewatered and saturated thickness decreases. Unless some source of recharge is nearby, the yield of 64.8 gpm is probably not sustainable. Data from Antigua.



180-Day Projection with No Recharge: Pumping Well Greencastle 5

EXTRAS

Why Pumping Tests?

1. Establish the Safe Yield of well
2. Calculate Aquifer Parameters – K, T, S, Sc etc.
3. Obtain representative Water Quality samples
4. Determine well's Recovery Characteristics
5. Select Pumps and Pumping Schedules
6. Estimate Zone of Capture (ZOC) & Wellhead Protection Area(WPA)
7. Determine effects, if any, on other nearby Wells, Wetlands, etc.
8. Determine if suspected Contaminant Threats are a problem

Types of Pump Tests

Step Test

- **Performed two or more days prior to the start of constant rate tests (allow for complete water level recovery to occur prior to start up of Constant Rate Test)**

- **Test usually includes from three to eight equal time pumping steps of from 90-120 minutes duration while incrementally increasing the discharge rate after each Step and keeping discharge rate constant during each step.**

- **Very important to measure drawdown frequently for bedrock wells to determine fracture dewatering depth (or install recording pressure transducer)**

- **May be the only real opportunity to overstress the well before putting on-line**

- **Analyze step test data and conduct step tests using formation and fracture location data**

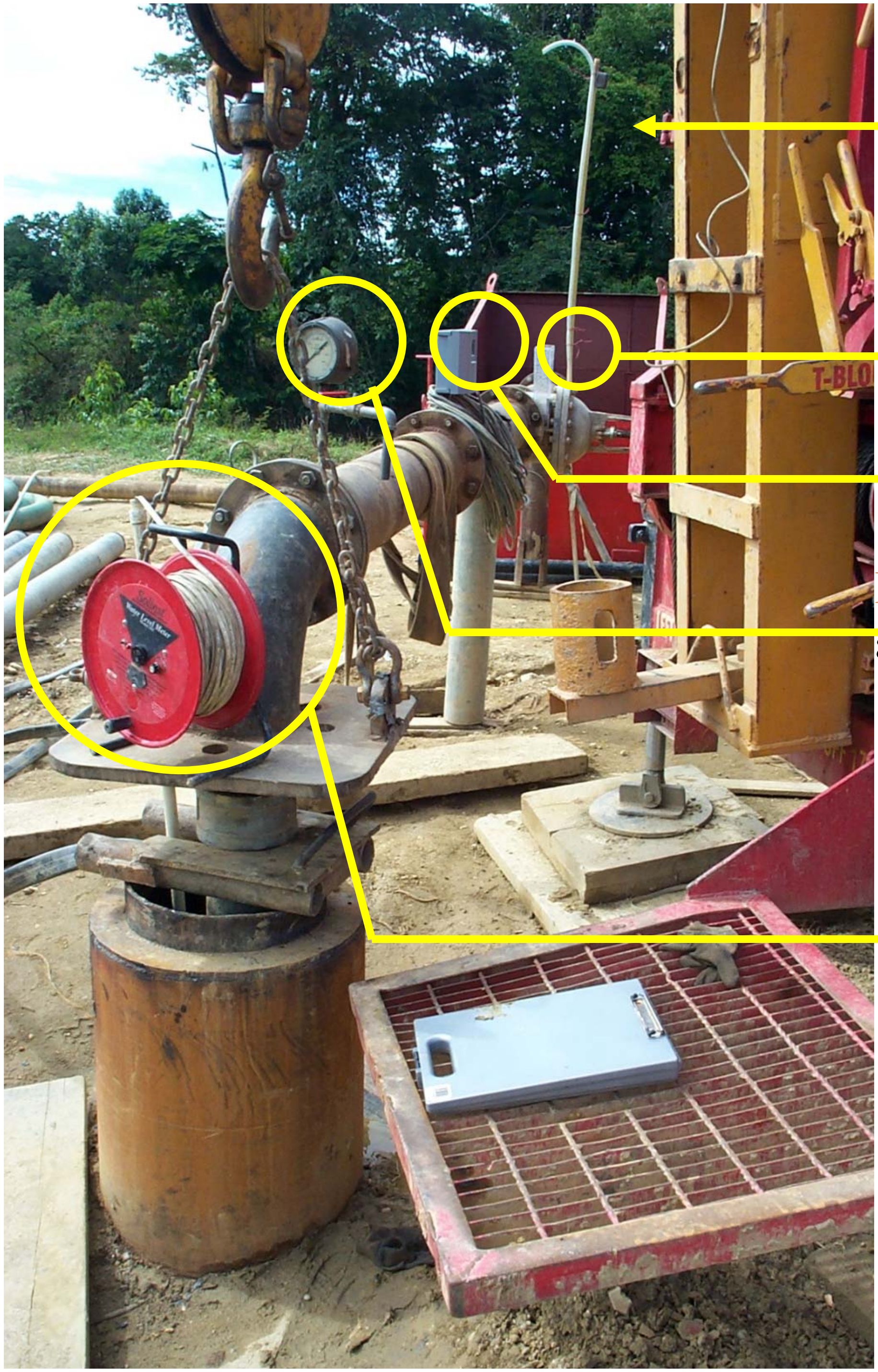
Constant Rate Test

- **Pumping rate fixed for duration of test – Testing continues for several days until the well water levels have reached complete stabilization or log stabilization**

- **Aquifer water levels, barometric pressure, rainfall and ambient monitoring well data collected prior to, during and after pumping for specified period of time.**

Pumping Test Set up-Trinidad

V-Notch Weir and Orifice Weir



Orifice Weir - Measures rate of flow using Pitot tube – pressure increases as flow increases

Rain Gauge - Collects rainwater to account for recharge during the test

Magnetic Flowmeter - Measures rate of flow of water through the pipe

Backpressure Gauge - Measures water pressure against gate valve

Water Level Probe – Measures water level drawdown during the test
(automatic recording downhole pressure sensing transducers are preferable)

At Constant-Rate-Pump Test Startup……

- Prior to start of the test, open the flow (gate) valve to achieve the desired flow for the first step as quickly as possible.
- One person should be monitoring pump discharge while another measures water levels. (If possible, purchase recording pressure transducers to make life easy)
- During the first few minutes of the test, drawdown may occur rapidly so it is important to check discharge frequently, and also calibrate discharge with a bucket and stopwatch.

If manually taking measurements use the following minimum recording schedule.

- First minute - at 30 and 60 seconds
- 1- 10 minutes - every minute
- 10 - 30 minutes - every 2 to 4 minutes
- 30 - 60 minutes - every 5 to 10 minutes
- After 60 minutes - every hour for first 24 hours
- For remainder of test period – 4 to 8 times per day

More frequently at end of test period …OR….Set Automatic reading transducers to record at 10 minute intervals throughout the remainder of the test period)

ZEROING IN ON SAFE YIELD

What if the pumping rate used for the constant rate test produces a 180-day water level projection that is too deep, or too shallow?

Two key aquifer parameters, transmissivity and storativity, can be calculated using test data.

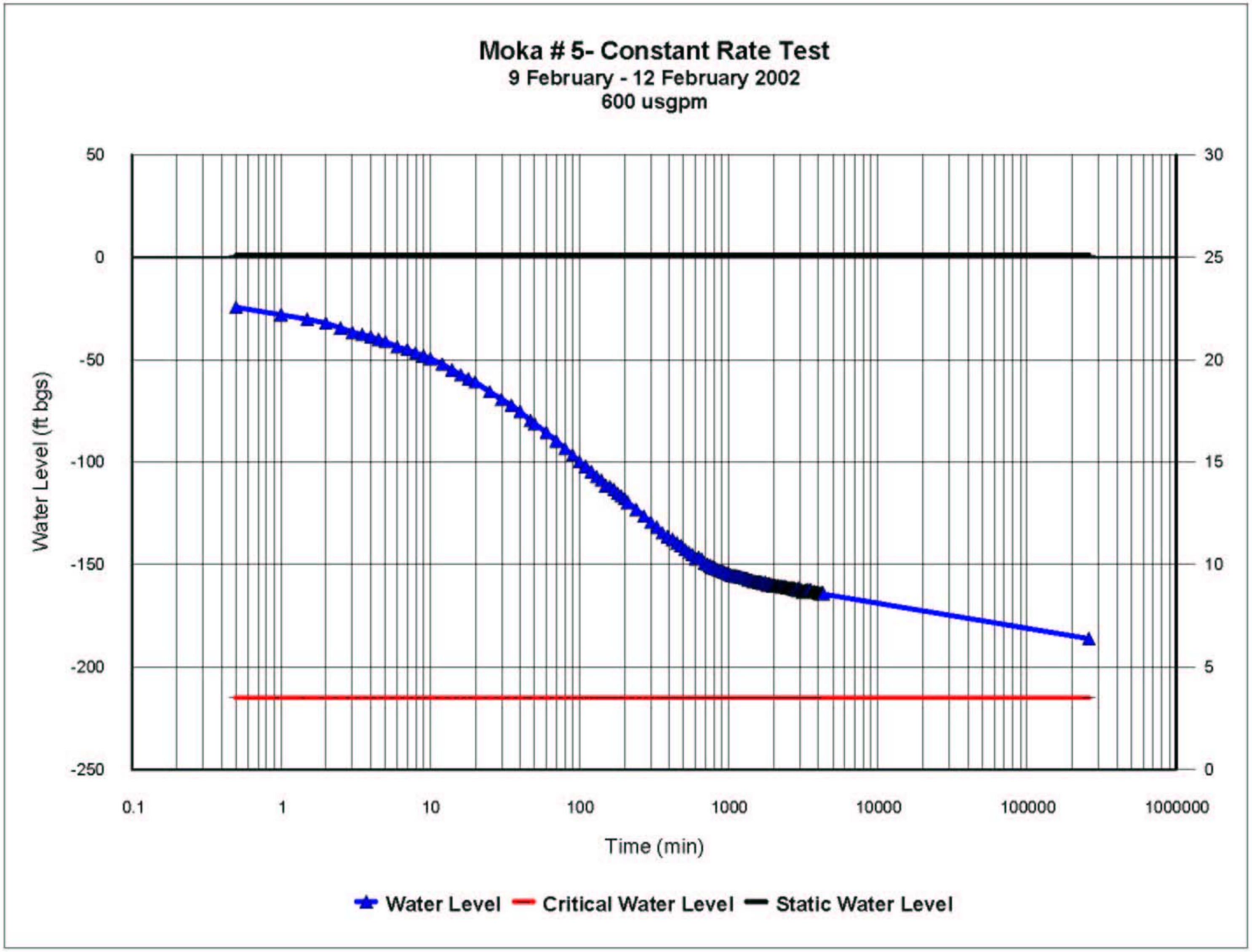
Parameter calculations are made using "analytical methods" (e.g., Theis or Jacob).

Same methods are then used to back-calculate the precise pumping rate corresponding with maximum allowable drawdown amount.

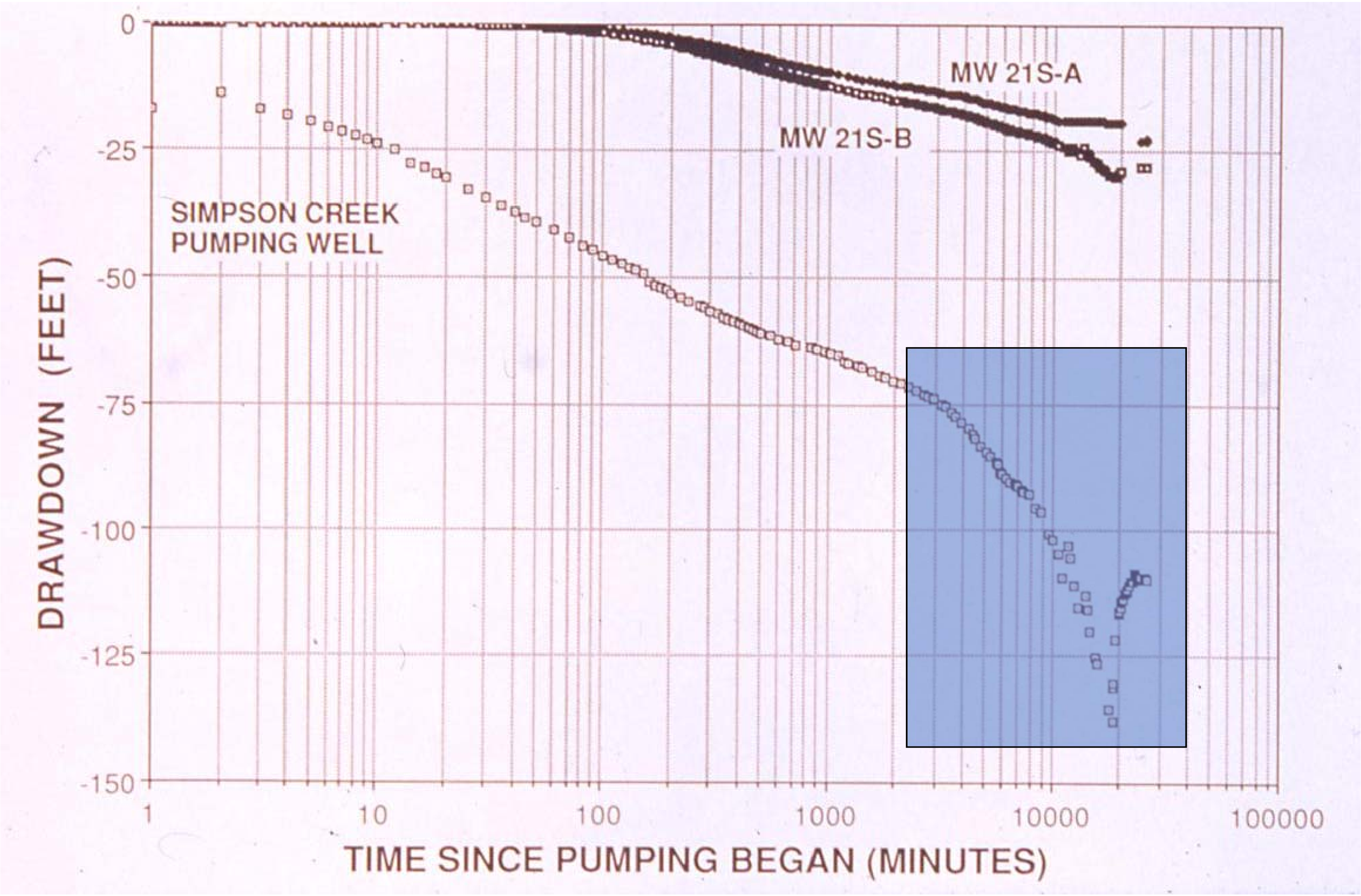
For hydrogeologically complex settings, or those involving higher-capacity water supplies, numerical flow models are frequently used to obtain more accurate and dependable assessments of safe yield.

600 US gpm Constant Rate Data

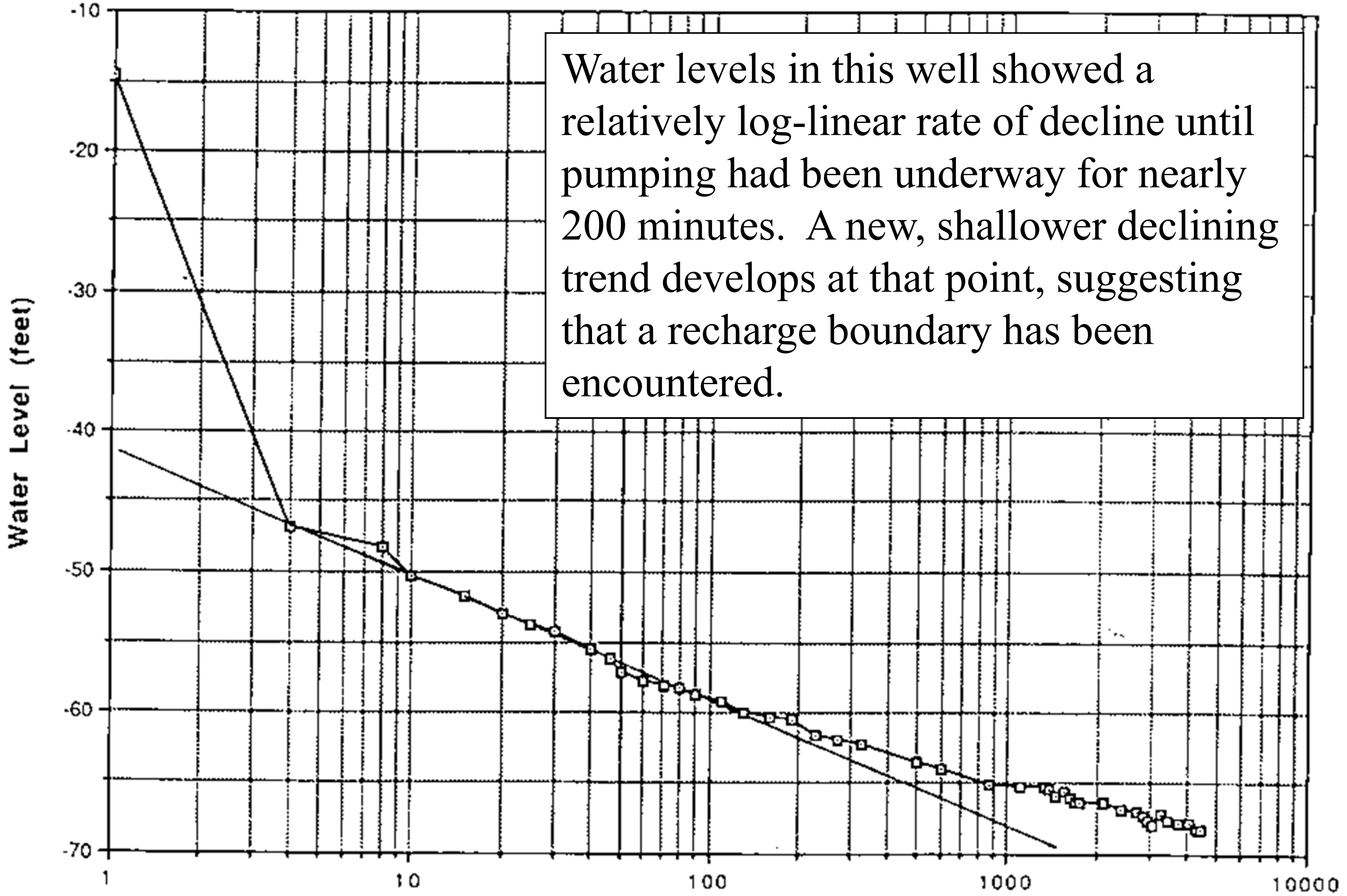
Water Level vs. Time



Fractured Bedrock Well- Constant Rate Test -255 GPM
Round Hill, VA – circa 1985

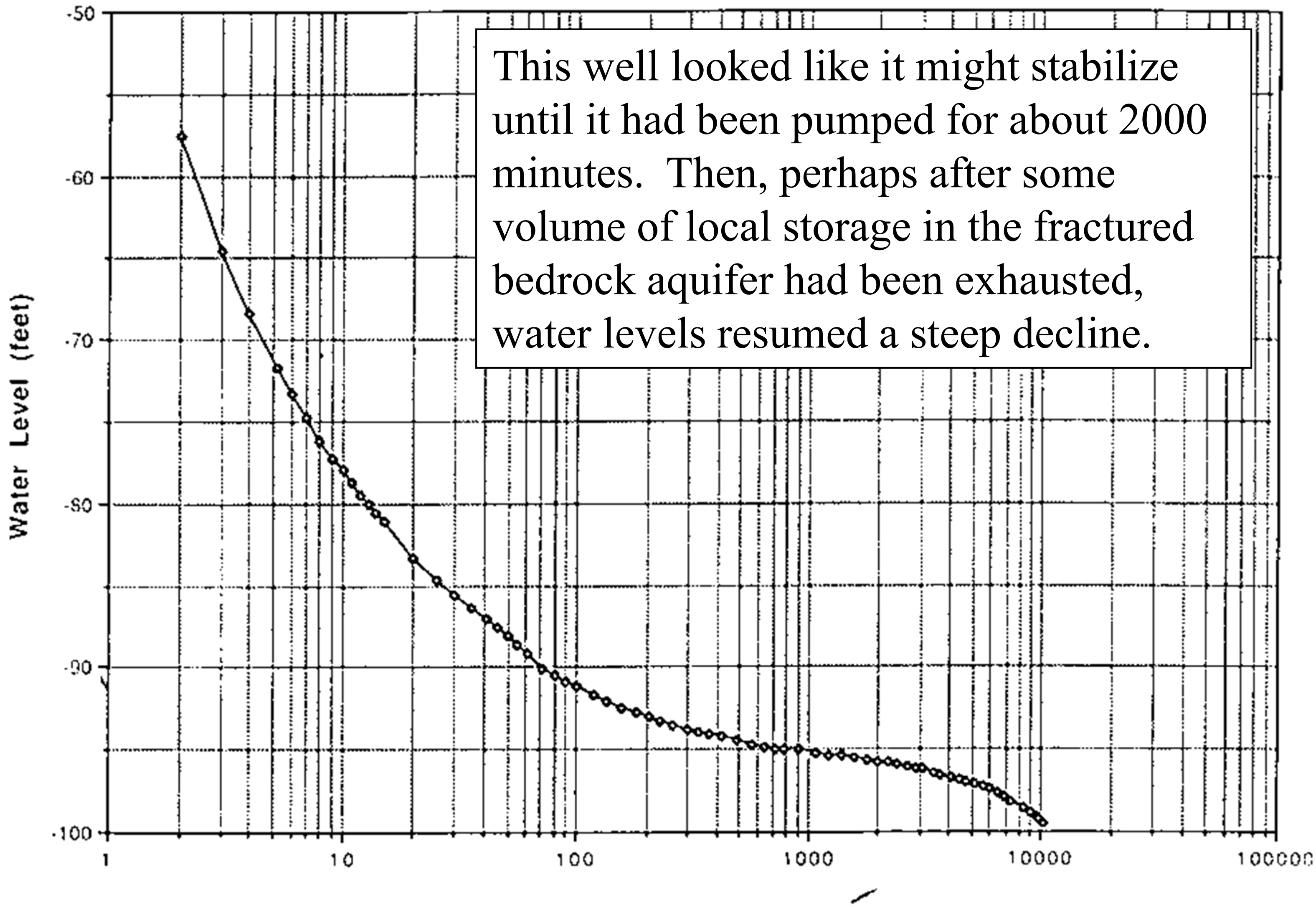


320+ GPM Fractured Bedrock Well
Constant Rate Test, 1982
Seabrook Water Supply Well #3 - Seabrook, NH



Water levels in this well showed a relatively log-linear rate of decline until pumping had been underway for nearly 200 minutes. A new, shallower declining trend develops at that point, suggesting that a recharge boundary has been encountered.

Semilog Graph, 750-GPM Constant Rate Test
Putnam, CT



CAN YOU TRUST THE TREND?

Using the prevailing end-of-test water level trend to project the 180-day water level carries the assumption that the trend would persist unchanged if pumping continued. A good assumption? Possibly, but with Exceptions

1. RECHARGE BOUNDARY ENCOUNTERED BEFORE END OF TEST

If drawdown "stops" before the end of the test, and the final trend of the water level data is horizontal, the cone of depression has expanded far enough to encounter a recharge boundary with recharge sufficient to exactly balance the withdrawal rate.

If the stabilized water level is far enough above the pump and highest water-bearing zones to give the desired margin of safety, the pumping rate is sustainable.

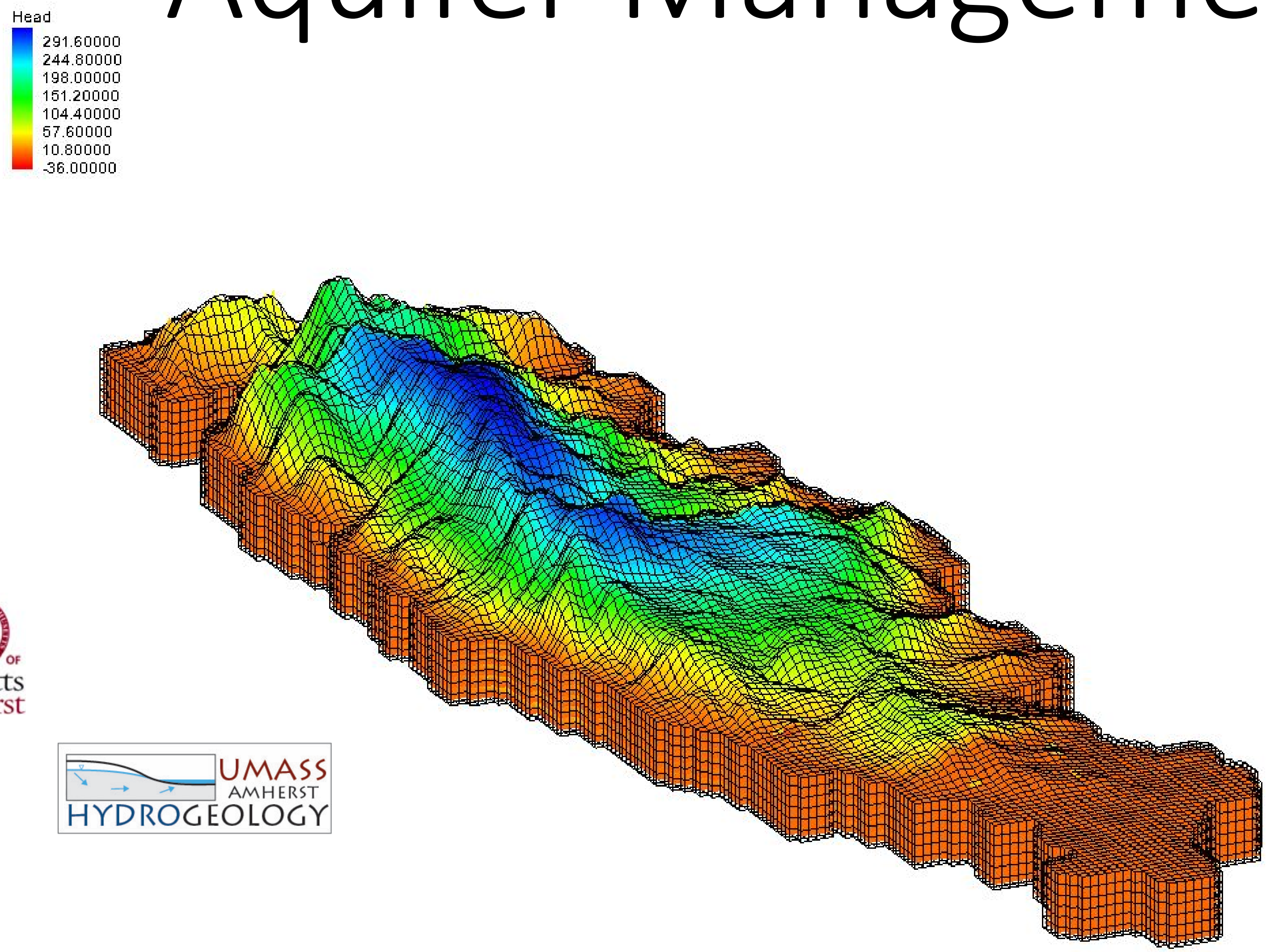
CAN YOU TRUST THE TREND?

2. RECHARGE BOUNDARY *NOT* ENCOUNTERED BEFORE END OF TEST

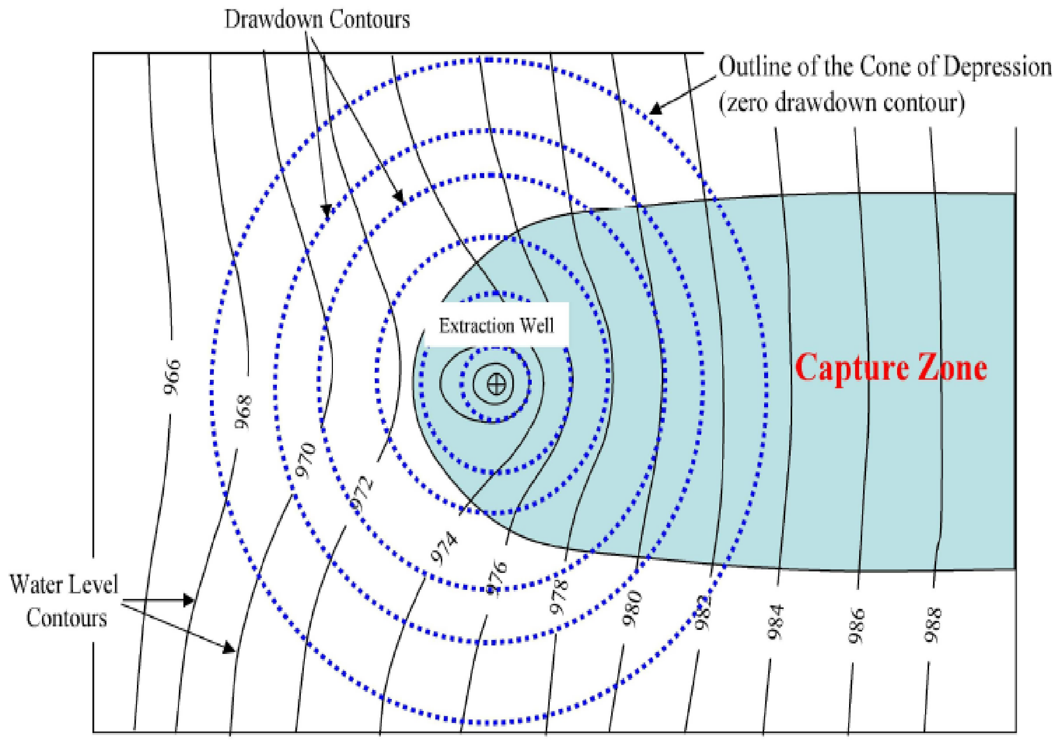
If the end-of-test water level trend is a decline, possibility remains that one or more boundaries would have been encountered if pumping continued-- either recharge (producing shallower rate of decline or water level stabilization) or barrier (producing steepening of water level decline, and more rapid-than-expected consumption of available drawdown).

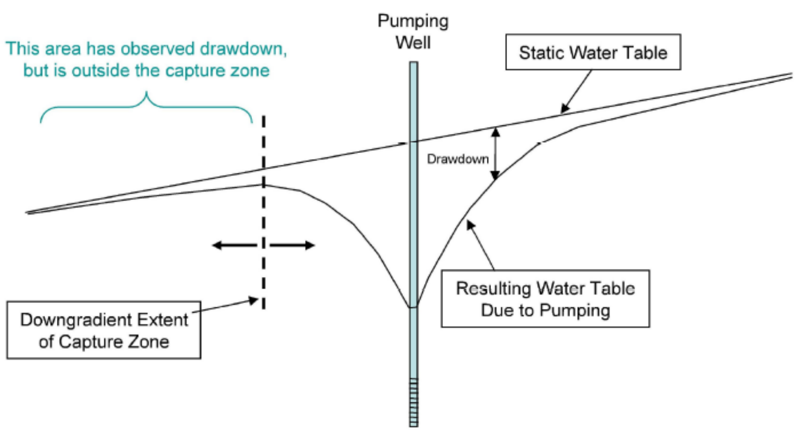
There's nothing in the pumping test data to predict when the next boundary might be encountered, so we fall back on what the conceptual model can tell us, and we err on the side of conservatism in estimating the well's safe yield to account for the added uncertainty.

Aquifer Management



Capture Zone vs. Drawdone Cone





Technical Base to Groundwater Management

- Identification of the recharge and discharge areas and connectivity of the aquifer system
- Characterization of hydrogeologic properties of aquifers, water quality, hydraulic heads and flow of groundwater
- Development of mathematical models of hydrogeologic behavior and risk analysis (vulnerability on local and regional scale)
- A network and information system that integrates groundwater date base (quantity and quality parameters, well characteristics, use and protection)