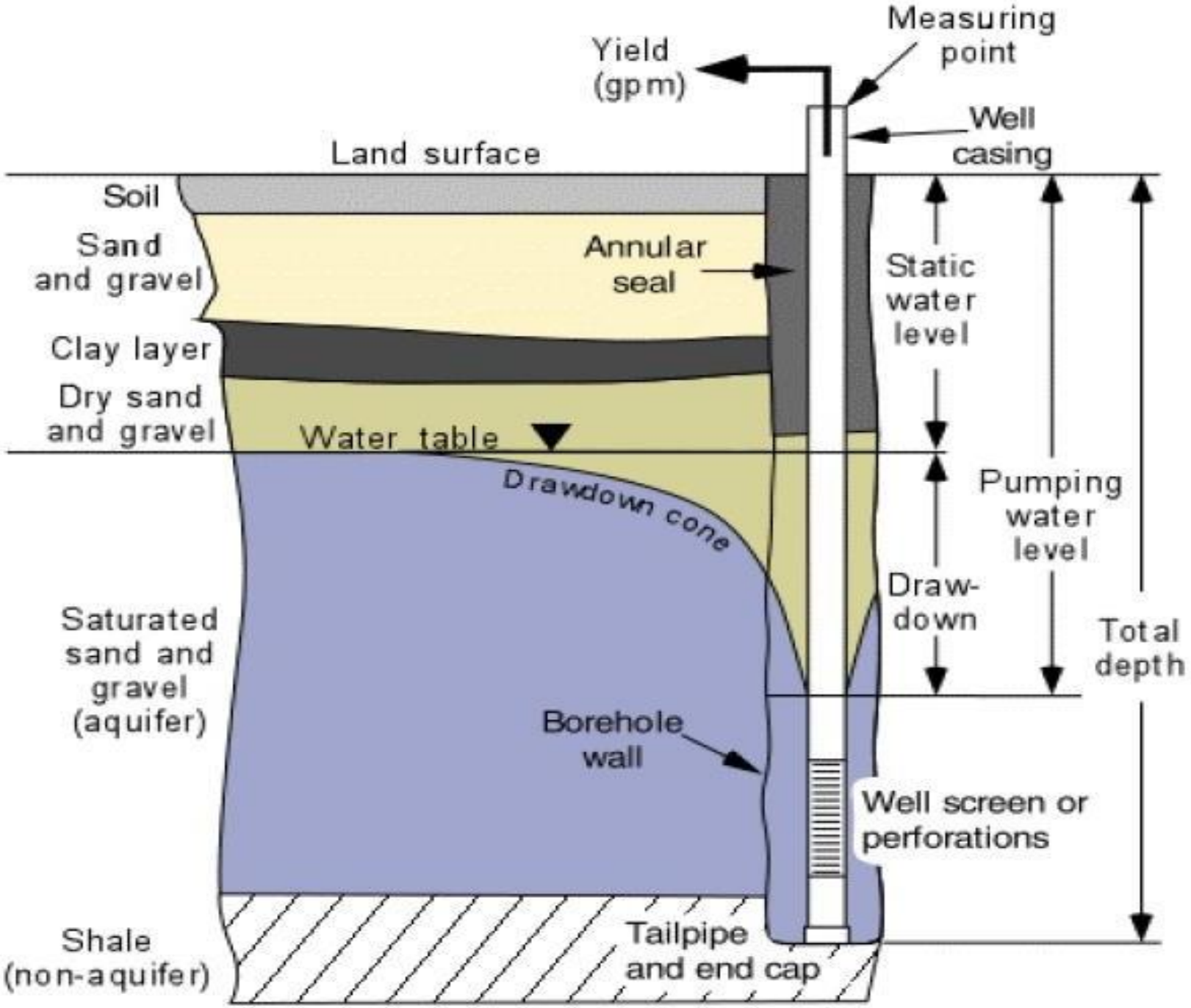
# WELL DESIGN


Measuring point
Yield (gpm)
Well casing
Land surface
Soil
Sand and gravel
Annular seal
Static water level
Clay layer
Dry sand and gravel
Water table
Drawdown cone
Pumping water level
Draw-down
Saturated sand and gravel (aquifer)
Total depth
Borehole wall
Well screen or perforations
Shale (non-aquifer)
Tailpipe and end cap

# Important terms

- Annular seal
- Aquifer
- Borehole
- Casing
- Drawdown
- Cone of depression
- Measuring point
- Pumping water level
- Screen or perforations
- Static water level
- Tailpipe and end cap
- Water table
- Total depth
- Yield

# Water Well Design

- Well design means selecting the proper dimensional factors for well structure and choosing the materials to be used in its construction
- Prime considerations of well design are:
  - a) Service life
  - b) Cost and
  - c)Performance
- A properly designed well serves the following:

a) Allows the water to enter at low velocity

b) Prevents the entry of sand

c) Serve as the structural retainer to support the loose formation material

# Water Well Design

- Length of screen
- Diameter of screen
- Slot openings of the screen
- Gravel pack material
- Yield of Tubewell

# Water Well Design

**Well Screen or Strainer:** Well screen is the part of well pipe which contains slot openings for extraction of water from water bearing strata.

A properly constructed well screen should –

- allow water to enter the well freely at low velocity,
- prevent sand from entering with the water, and
- serve as the structural retainer to support the loose formation material.

# Water Well Design

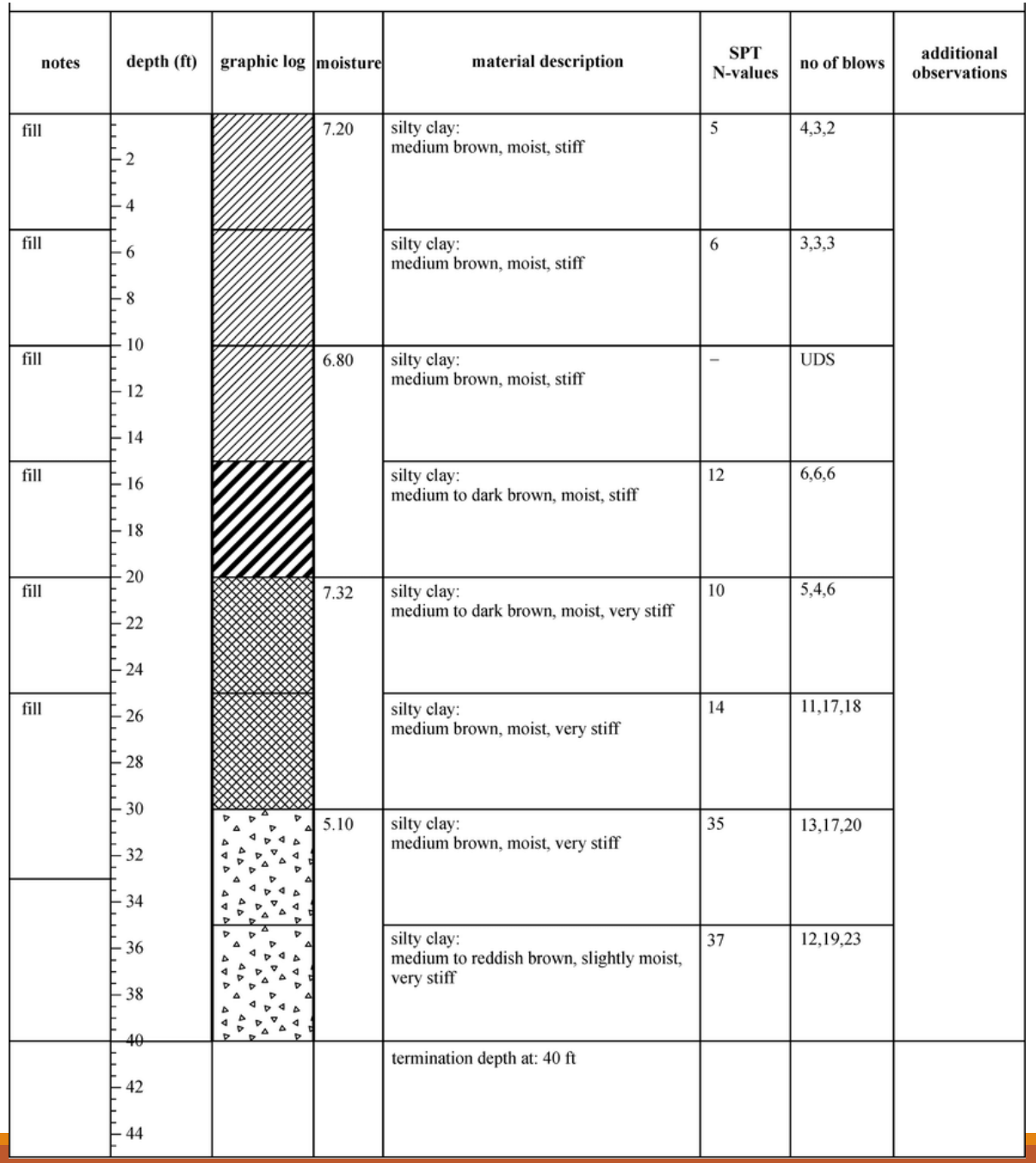
The length and position of the strainer must be evaluated carefully.

Following four factors to be considered while determining the position of the well screen

1. Existing static water level at present
2. Assumed drawdown of 10-20 ft while pumping
3. Average rate of water level declination per year x design period
4. Extra allowance of 10-15 ft depth for safety

That means the position of the screen should start after providing blank casing up to the extent equal to the sum of the above four values

# Bore Log



| notes | depth (ft) | graphic log | moisture | material description | SPT N-values | no of blows | additional observations |
|---|---|---|---|---|---|---|---|
| fill | 2–4 | | 7.20 | silty clay: medium brown, moist, stiff | 5 | 4,3,2 | |
| fill | 6–8 | | | silty clay: medium brown, moist, stiff | 6 | 3,3,3 | |
| fill | 10–12 | | 6.80 | silty clay: medium brown, moist, stiff | – | UDS | |
| fill | 14–16 | | | silty clay: medium to dark brown, moist, stiff | 12 | 6,6,6 | |
| fill | 18–20 | | 7.32 | silty clay: medium to dark brown, moist, very stiff | 10 | 5,4,6 | |
| fill | 22–24 | | | silty clay: medium brown, moist, very stiff | 14 | 11,17,18 | |
| | 26–28 | | 5.10 | silty clay: medium brown, moist, very stiff | 35 | 13,17,20 | |
| | 30–32 | | | silty clay: medium to reddish brown, slightly moist, very stiff | 37 | 12,19,23 | |
| | 34–36 | | | | | | |
| | 38–40 | | | | | | |
| | 42–44 | | | termination depth at: 40 ft | | | |

# Most Productive Aquifer

The intake portion of the well must be placed in those zones having the highest hydraulic conductivity which is determined using following technique:

- Aquifer materials at definite intervals undergo sieve analysis.
- Particle size distribution curve is prepared.
- Effective size ($d_{10}$) and uniformity coefficient($C_U=d_{60}/d_{10}$).
- Aquifer materials having high effective size $d_{10}$ and low uniformity coefficient $C_U$ will have high hydraulic conductivity.
- Best aquifer for screening is determined by comparison of the grain size analysis curve of the materials along the depth of the borehole.

# Well Screen Slot Openings

- Oversized slots will pump finer materials indefinitely and become difficult to obtain clear water. Undersized slots will provide more resistance to flow of groundwater into the well, resulting in more head loss and corrosion.
- Screen slot openings for the same formation can be different depending on whether the well is naturally developed or filter packed.
- Coarse-grained non-homogeneous material can be developed naturally, whether fine-grained homogeneous materials are best developed using a filter pack.



PVC screens available from 33mm diameter to 630mm diameter

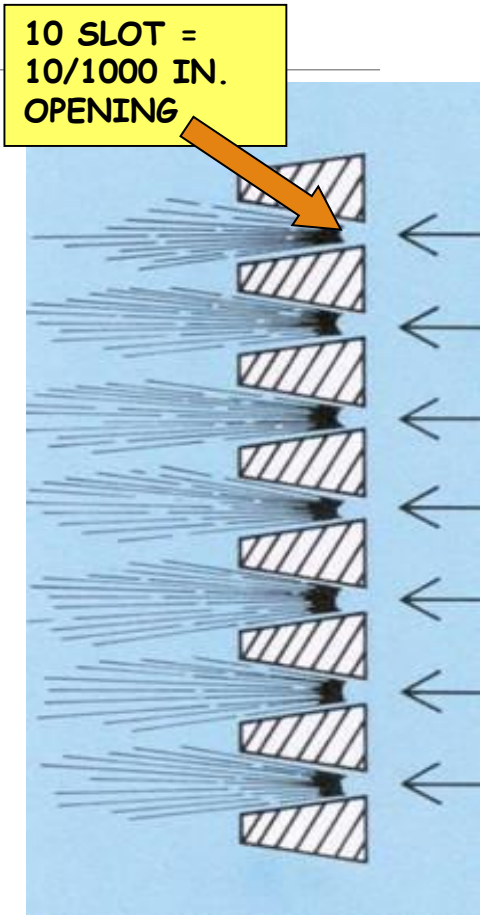


Stainless Steel Water Well Screen

# Screen Slot Size

Screen Slot Sizes are measured in thousandths of an inch

- Slot No. 5 = 5/1000 inch = 0.005 inch
- Slot No. 10 = 10/1000 inch = 0.010 inch
- Slot No. 20 = 20/1000 inch = 0.020 inch
- Slot No. 30 = 30/1000 inch = 0.030 inch
- Slot No. 40 = 40/1000 inch = 0.040 inch
- Slot No. 60 = 60/1000 inch = 0.060 inch
- Slot No. 80 = 80/1000 inch = 0.080 inch




CROSS-SECTION
OF SCREEN WIRE

# Well Screen Diameter

- Increasing screen length is generally more effective than increasing screen diameter for enhancing well yield.
- Doubling the screen diameter, for instances, will only result in increasing 10% to 15 % in the yield. On the other hand, doubling the screen length will result in the yield being almost doubled.
- It is much more better to use screen length as a controlling factor on well rather than screen diameter in thick aquifer.
- Enough open area must be provided so that the entrance velocity of water generally does not exceed the design standard of **0.1 ft/s**.

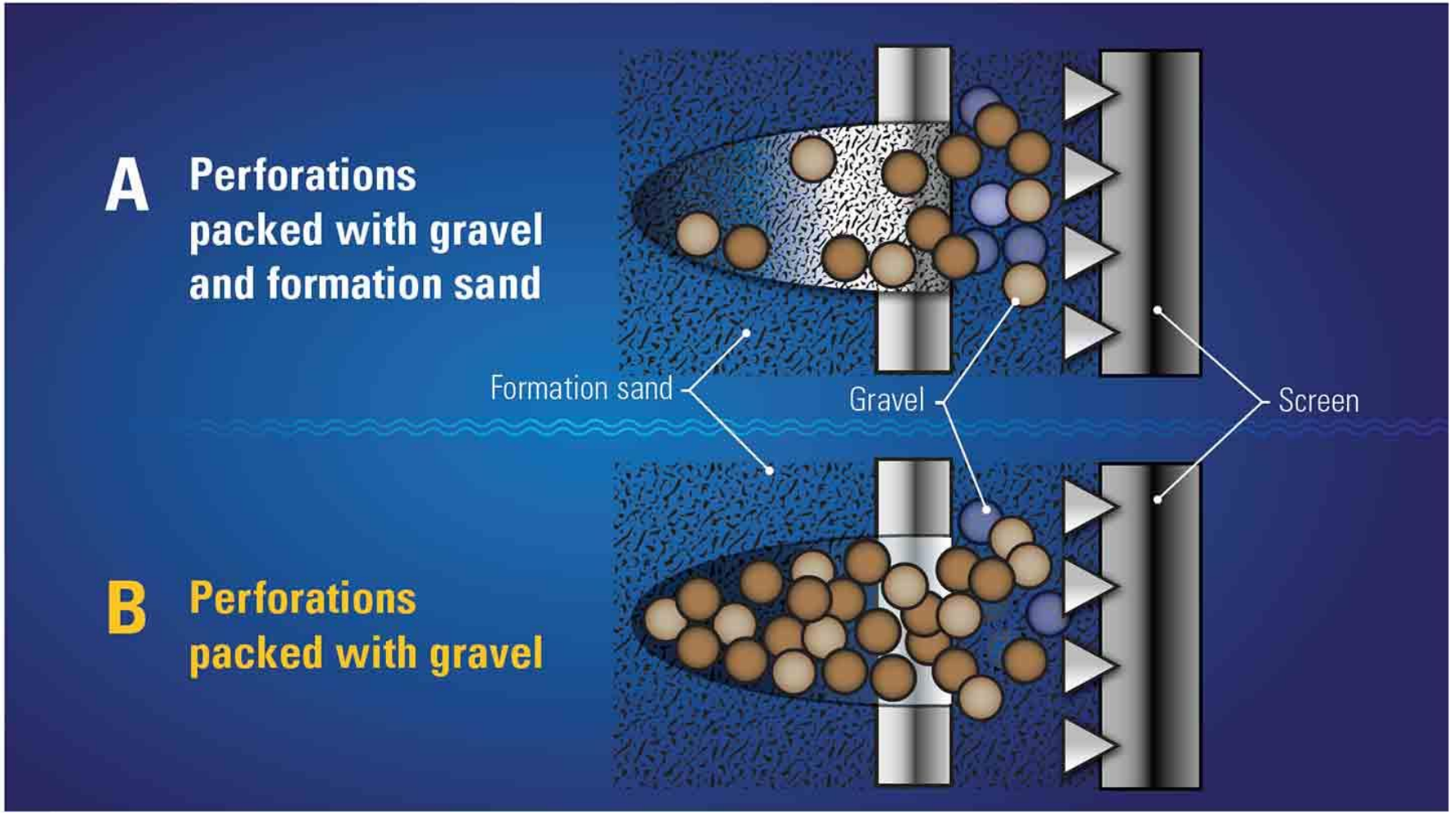
# Gravel Pack Design

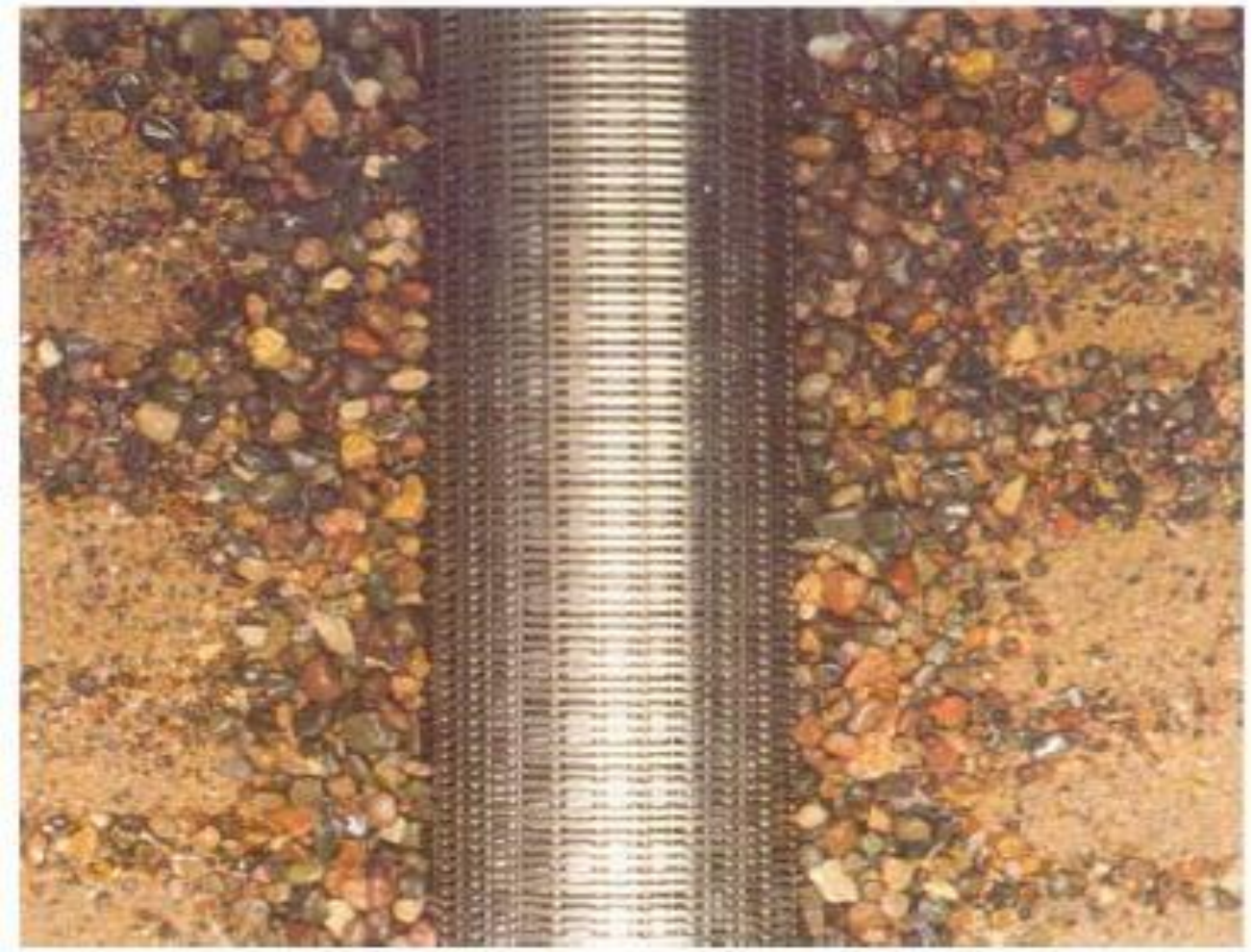
- Gravel pack materials should be well sorted to assure good porosity and hydraulic conductivity of the materials near the screen.

Gravel packing is required when:

- The sediments are highly uniform and fine grained ($d_{10}$<0.25mm).
- The sediments are highly laminated.
- The borehole diameter may be much larger than required for the installation of a screen.

Selecting a screen slot size that will retain 90% or more of the filter pack material. The thickness of the filter pack should be within 3 to 8 inches .


A
Perforations
packed with gravel
and formation sand
Formation sand
Gravel
Screen
B
Perforations
packed with gravel



Natural Garvel Pack Material

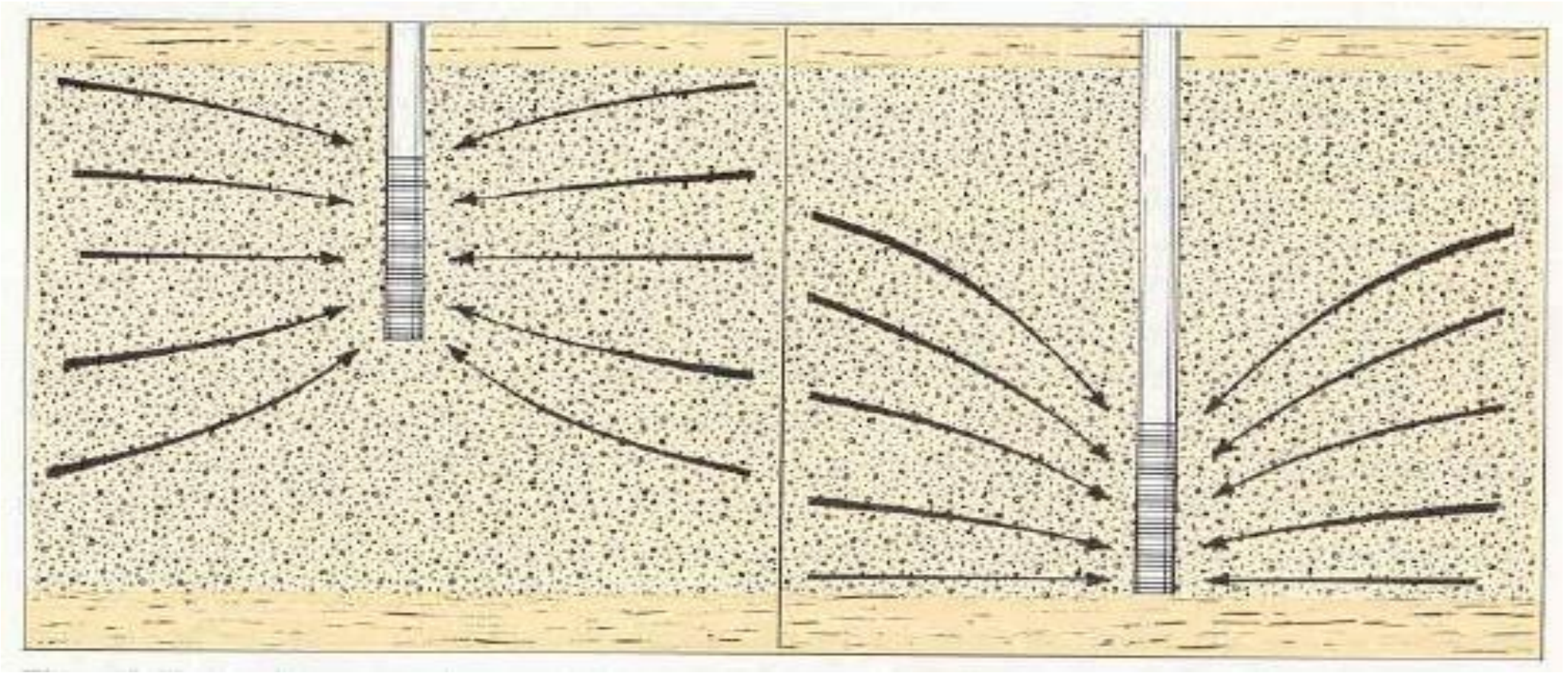
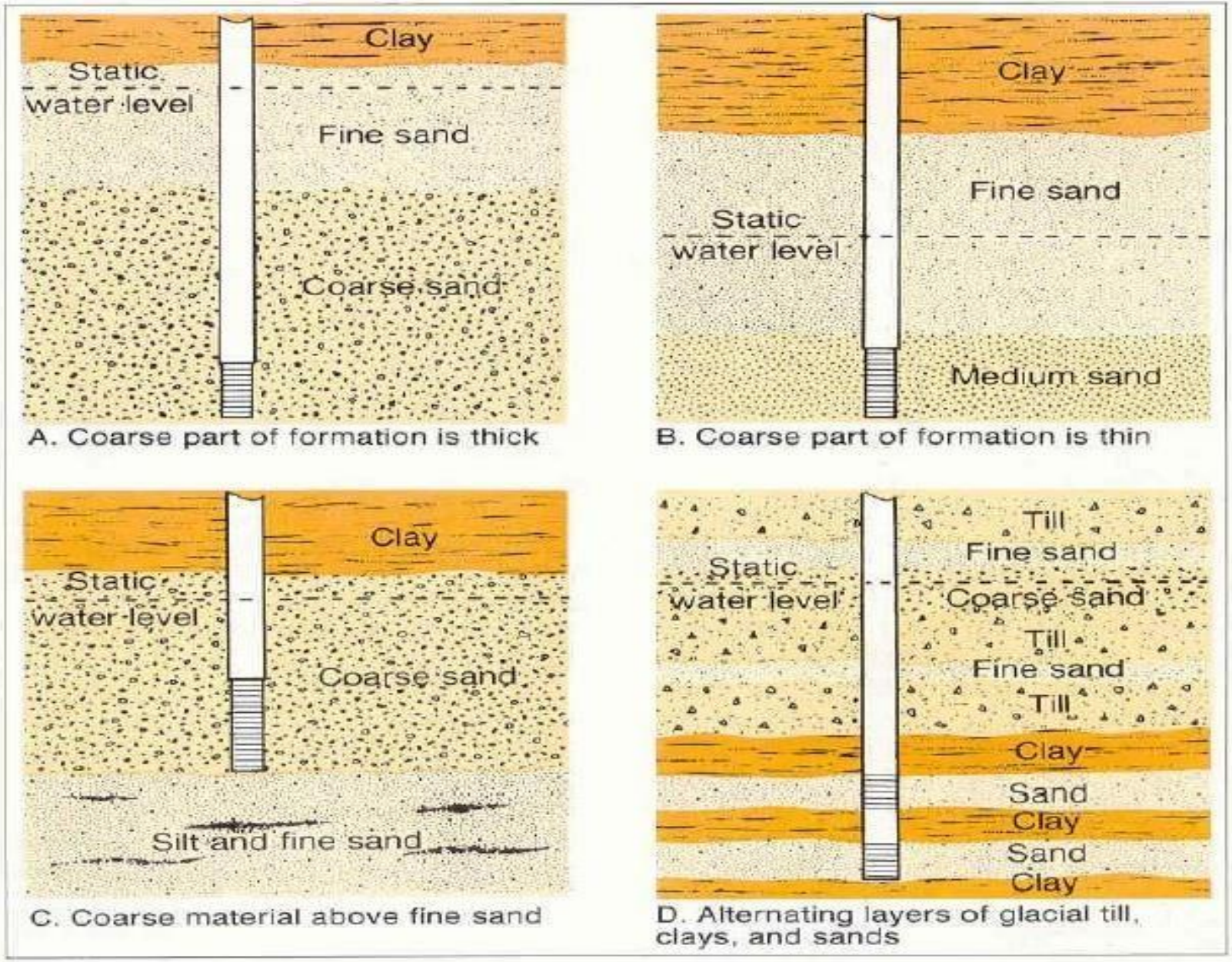


**Figure** partial penetrations when the intake portion of the well is less than the full thickness of the aquifer. This causes distortion of the flow lines and greater head losses.






Suggested positioning of well screens in various stratified water-bearing formations

# Entrance Velocity

- Field experience and laboratory tests show that the average entrance velocity of water moving into the screen should not exceed **0.1ft/s**.
- At this velocity, the friction losses in the screen openings will be negligible and the rates of incrustation and corrosion will be minimal.

# Screen Transmission Capacity

The transmitting capacity of a well is given by,

- $Q=\pi DL(0.01p)v_c$

Where, Q=screen transmitting capacity

D=diameter of the screen

L=length of the screen

p=percent opening area of the screen

$v_c$=permissible entrance velocity

The discharge of a tubewells should not exceed the transmitting velocity.

## Example - 1

Design a strainer for a 38 mm diameter tubewell to be operated by a No.6 handpump at the rate of 40 lpm. Slot No.10 strainer having a 40% open area is to be used. The entrance velocity should be around 0.01 m/sec.

**Solution:** The open area per metre of 38 mm strainer = $\pi d \times 1 \times 0.04 = 3.14 \times 0.038 \times 1 \times 0.4 = 0.0477\ m^2/m$

$Q = 40$ lpm $= (40/60) \times 10^{-3}\ m^3/sec. = 0.67 \times 10^{-3}\ m^3/sec.$

Entrance Velocity, $v_e = 0.01$ m/sec.

Entrance area required $= Q/v_e = 0.67 \times 10^{-3}/0.01 = 0.067\ m^2$

Length of the strainer required $L = 0.067/0.0477 = 1.4$ m

Strainer length of 1.5 m may be provided.

# Steps for well design

1. Grain size distribution for different soil layers
2. Locating the aquifer and water bearing strata
3. Determination of strainer length and position
4. Design of gravel pack material
5. Selection of strainer size
6. Yield of well

## 1. Grain size distribution for different soil layers

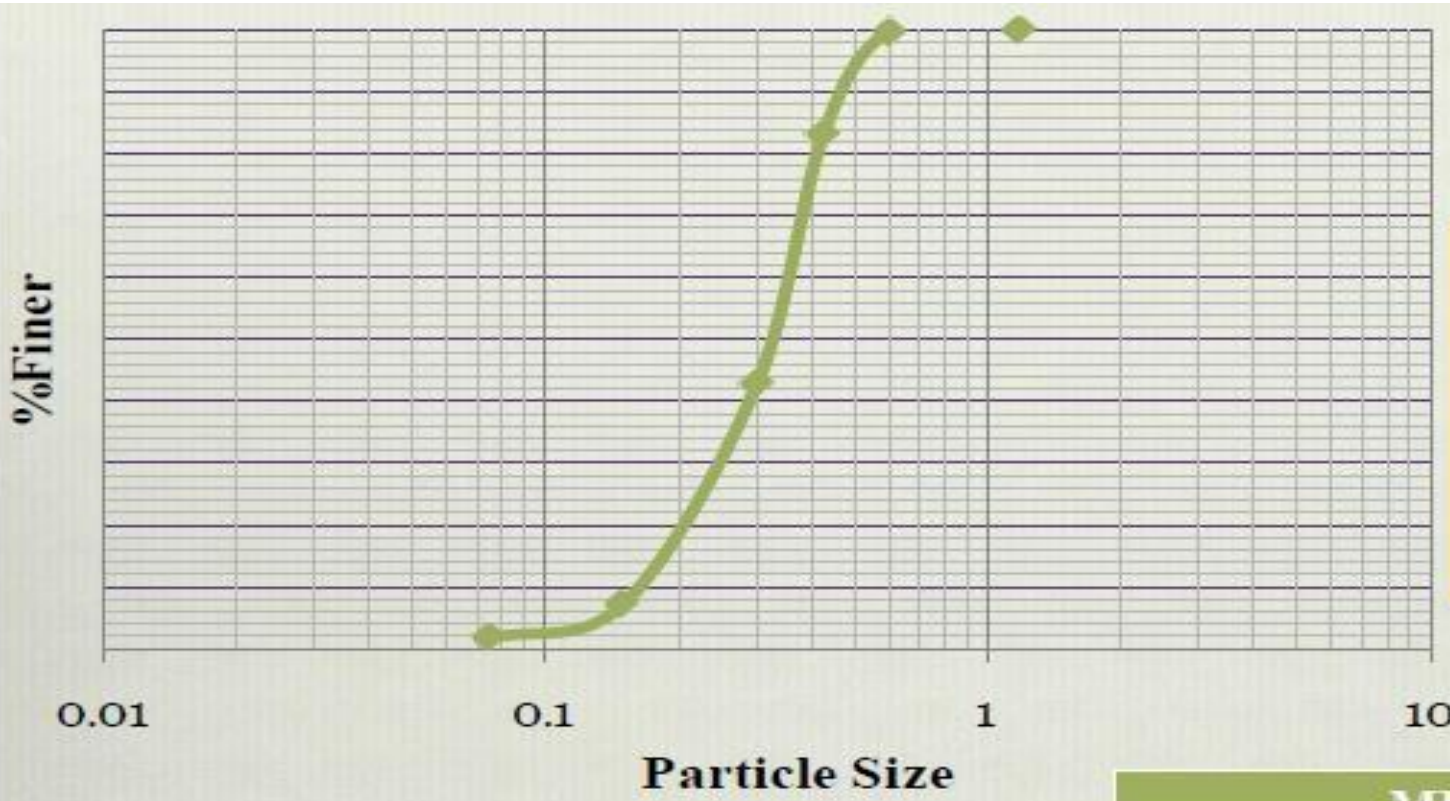
- Grain size distribution curves are drawn for different soil layers using soil data
- Effective grain size ($D_{10,}$ $D_{30,}$ $D_{60}$) and uniformity coefficient are found for each layer
- From the grain size distribution curves relative percentage of different particles are found using MIT classification of soil

# 1. Grain size distribution for different soil layers

## Sample Calculation

| Sieve No | Seive Size (mm) | Material Retained | % Retained | Cumulative % Retained | %Finer | FM |
|---|---|---|---|---|---|---|
| 16 | 1.18 | 0 | 0 | 0 | 100 | |
| 30 | 0.6 | 0.2 | 0.2 | 0.2 | 99.8 | |
| 40 | 0.425 | 16.4 | 16.47 | 16.67 | 83.33 | |
| 50 | 0.3 | 40.4 | 40.56 | 57.23 | 42.77 | 1.5 |
| 100 | 0.15 | 35.4 | 35.54 | 92.77 | 7.23 | |
| 200 | 0.075 | 5.6 | 5.62 | 98.39 | 1.61 | |
| Pan | 0.0001 | 1.6 | 1.61 | 100 | 0 | |
| Total | | 99.6 | | | | |

- $FM = \frac{\sum(\text{Cumulative \% retained of standard sieves})}{100}$




Fine Sand 20%
Medium Sand 79%
Course Sand 1%

| MIT Classification | |
|---|---|
| Silt/Clay | < 0.06 mm |
| Fine Sand | 0.06 – 0.20mm |
| Medium Sand | 0.20 – 0.60 mm |
| Course Sand | 0.60 – 2.00mm |
| Fine Gravel | > 2.00 mm |

## 2. Locating the aquifer and water bearing strata

- All soil sample data are summarized in a table to find available water bearing soil strata

**Factors to be considered for locating water bearing strata**

- Greater uniformity coefficient increases permeability
- Higher fineness modulus means bigger soil particle
- Higher percentage of course and medium sand indicates higher water carrying capacity
- FM<1 → Clay and silt

  FM=1 → Fine sand with silt

  FM>1→ Medium to course sand which has potential to good permeability and presence of water

# 1. Locating the aquifer and water bearing strata

## Summary of Grain Size Distribution

| Sample Depth (ft) | D10 | D30 | D60 | U = $D_{60}$ / D10 | FM | % Course Sand | % Medium Sand | % Fine Sand |
|---|---|---|---|---|---|---|---|---|
| 130-170 | 0.15 | 0.195 | 0.27 | 1.80 | 1.18 | 1 | 66 | 33 |
| 170-210 | 0.12 | 0.195 | 0.3 | 2.50 | 1.26 | 3 | 67 | 30 |
| 210-220 | 0.15 | 0.21 | 0.33 | 2.20 | 1.41 | 4 | 70 | 26 |
| 220-270 | 0.17 | 0.28 | 0.3 | 1.76 | **1.63** | **6** | **77** | 17 |
| 270-310 | 0.17 | 0.28 | 0.31 | 1.82 | **1.69** | **11** | **72** | 17 |
| 310-370 | 0.17 | 0.24 | 0.38 | 2.24 | **1.5** | **5** | **75** | 20 |
| 370-410 | 0.17 | 0.29 | 0.395 | 2.32 | **1.63** | **5** | **80** | 15 |
| 410-430 | 0.15 | 0.22 | 0.37 | 2.47 | 1.47 | 5 | 71 | 24 |

***Higher %of coarse and medium sand**
***Higher FM means bigger particle**

**Location of water bearing soil layer 220' to 410'**

## 3. Determination of strainer length and position

Primary factors:

1. Length of casing pipe must be selected first
2. Casing pipe must be sufficient enough so that submersible pump always remain below water

Length of the casing pipe is the summation of four lengths:

1. Static water level at present
2. Assumed drawdown of 10' to 15' while pumping each time
3. Average rate of water level declination (per year) x Design life
4. Safety distance of 10' to 15'

- After the length of the casing pipe and depth of the submersible pump being ensured, we can think about strainer position
- Limitation of strainer length

| Aquifer Thickness | Recommended Screening |
|---|---|
| < 25' | 70% Screening |
| 25' – 50' | 75% Screening |
| > 50' | 80% Screening |

- As it is very difficult to maintain the vertical alignment of a long strainer, it will not be practical to go beyond 100' screening
- Strainer should not be extended up to the bottom of the aquifer to allow the upward converging flow of water during pumping

Necessity of a blank pipe

1. Between two strainers of a discontinuous aquifer
2. 10’ blank pipe is placed at the bottom of the strainer to trap particles that may enter into the pipe through upward converging flow

**Sample Calculation**

Let, the static water level at 230’

Average rate of water level declination (per year) = 2’

Design period= 20 years

Drawdown of 15’ while pumping each time

Safety distance of 15’

So length of the casing pipe= (230+40+15+15)= 300’

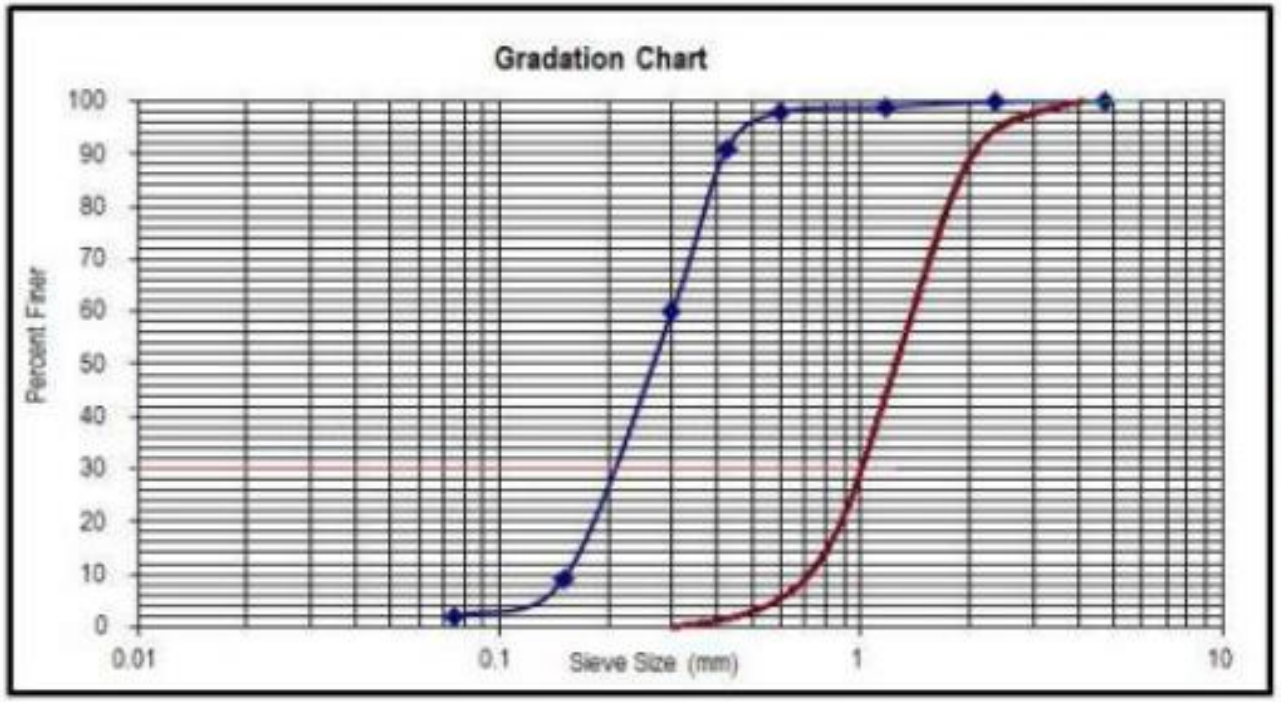
Aquifer depth= (410-220) = 190’ which is more than 50’.

So 80% of the aquifer screening can be made which gives the strainer length of = (190 * 0.80) = 152’

But as we know that maximum safe length of the strainer is 100’, so we can choose a strainer of 100’

## 4. Design of gravel pack material

- To design the gravel pack material, the grain size distribution curve of the comparatively finest layer within the aquifer is drawn on a semi log paper
- 70% ($D_{30}$) size of the finest sand is multiplied by a factor 4-6 depending on the sand type. This is the first point on the curve that represents the grading of the artificial gravel pack material.
- Through this initial point on the gravel pack curve, a smooth curve nearly parallel with the aquifer material curve is drawn by trial and error method, representing a material with a uniformity coefficient 2.5 or less.




As Cu of the finnest layer in between 1.5 & 2.5, assume multiplying factor = 4.5
D30 of gravel pack = 1.0 mm
Cu = 2.1 < 2.5, OK

## Gravel Pack Material:

| Sieve Number | Sieve Opening (mm) | Cumulative % Retained | Pertinent Values |
|---|---|---|---|
| 8 | 2.36 | 0-12 | |
| 16 | 1.18 | 2-18 | FM = 3.65 |
| 30 | 0.6 | 28-42 | $D_{10}$ = 0.73 |
| 40 | 0.425 | 90-100 | $D_{60}$ = 1.5 |
| 50 | 0.3 | 100 | U= 1.75 |

# 4. Design of Gravel Pack Material
# 5. Selection of Strainer Size

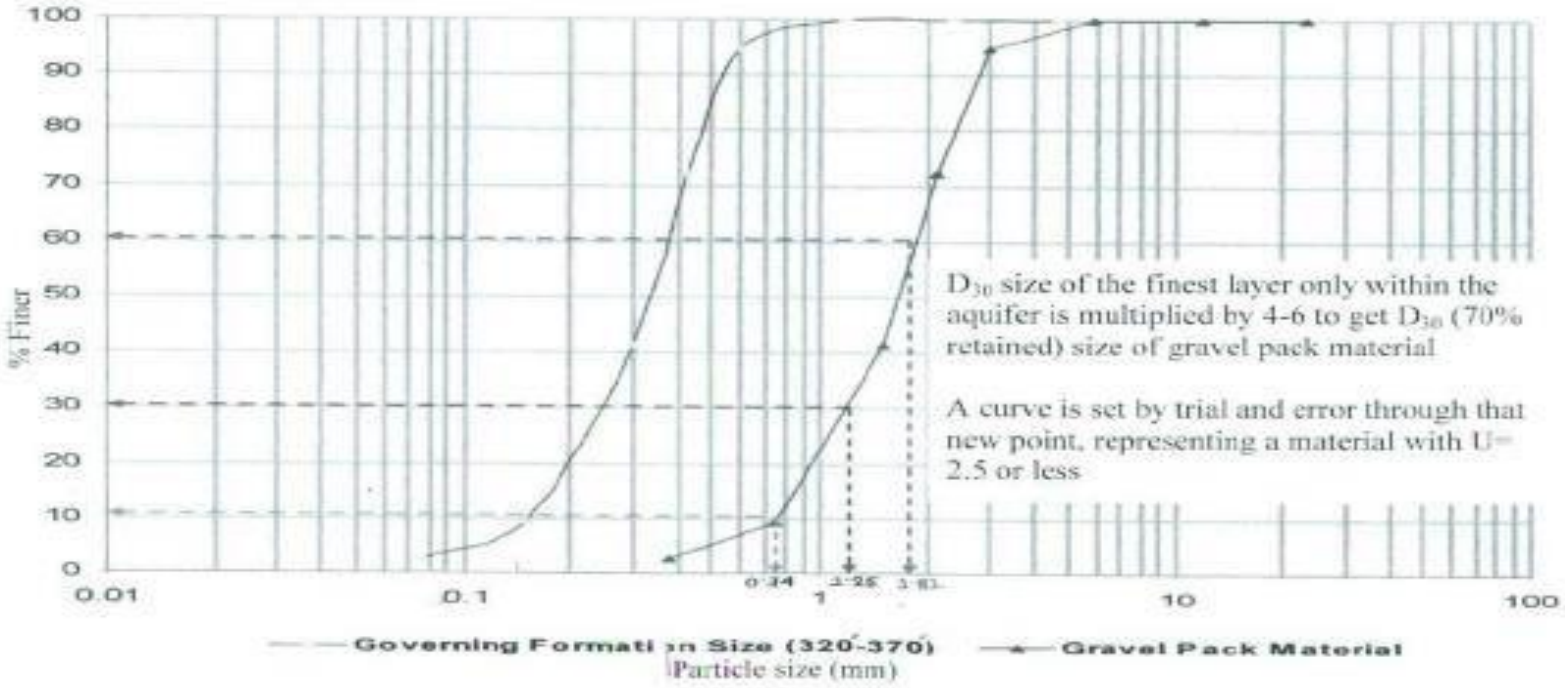
## Gravel Pack Material

| Sieve No. | Size(mm) | % Finer from Graph | Cumulative % Retained | % reatained | Range of % reatained |
|---|---|---|---|---|---|
| 4 | 4.75 | 98 | 2 | 2 | 0-6 |
| 8 | 2.36 | 80 | 20 | 18 | 14-22 |
| 16 | 1.18 | 28 | 72 | 54 | 50-58 |
| 30 | 0.6 | 5 | 95 | 23 | 19-27 |
| 40 | 0.425 | 3 | 97 | 2 | 0-6 |
| 50 | 0.3 | 0 | 100 | 3 | 0-7 |
| 100 | 0.15 | 0 | 100 | 0 | - |
| 200 | 0.075 | 0 | 100 | 0 | - |

## Strainer Size

To retain 90% of gravel pack materials, slot= $D_{10}$ /25.4*1000
=0.74/25.4*1000
=29.13

4-6 inch dia 30 slot strainer is selected having each opening area of 30/1000 inch




$D_{30}$ size of the finest layer only within the aquifer is multiplied by 4-6 to get $D_{30}$ (70% retained) size of gravel pack material

A curve is set by trial and error through that new point, representing a material with U= 2.5 or less

**3-8 inch diameter envelop of gravel will surround the entire screen**

Specification for the gravel pack material is prepared by

- first selecting 4 to 5 sieve sizes that cover the spread of the curve and then
- set down a permissible range (±8%) for the percent retained on each of the selected sieves.

Gravel pack material should be clean and well rounded.

To ensure that an envelope of gravel will surrounded the entire screen, a thickness from 3- 8 inch can be maintained.

## 5. Selection of strainer size

To retain 90% of the gravel pack materials,

Slot = $D_{10}$ / 25.4 * 1000 ; here $D_{10}$ will be of the gravel pack material

If, $D_{10}$ = 0.74 mm

Slot= 0.74/ 25.4 * 1000 = 29.13

So 4-6 inch diameter 30 slot strainer is selected having each opening area of 30/1000 inch

3 to 8 inch diameter envelop of gravel pack material will surround the entire screen

## 6. Yield of well

- Well yield is calculated using strainer opening area
- Yield = (area of strainer x flow velocity) / factor of safety
- The factor of safety is considered assuming blockage while operation
- Different slot size have different opening area
- For PVC screen, opening area is considered to be half of the mentioned areas below

| Slot size | Assumed opening (Steel screening) |
|---|---|
| 40 slot | 20% |
| 30 slot | 15% |
| 20 slot | 10% |

**Sample calculation**

For 30 slot strainer,

Strainer area= 15% of strainer surface area

= 0.15 x 3.14 x Diameter x Strainer length

Here, Diameter = 6”

Length = 100’

Assume, flow velocity = 0.10 fps

Screen blockage factor = 0.4

So, Yield of a well = (0.15 x 3.14 x 6/12 x 100 x 0.1) x 0.4

= K x $(0.3048)^3$ x 3600 x 1000

= 96,028 lph

Design considerations:

- For one pump
- In one day
- 10 hour pumping in two shifts

As pumping is for 10 hour per day, Yield = 96,028 x 10

= 960, 280 lpd

- More than one well may be required if one well can't meet the demand
- Water demand for that area = 1470800 lpd

No. of tubewells required = 1470800 / 960280 = 1 . 5 ≈ 2

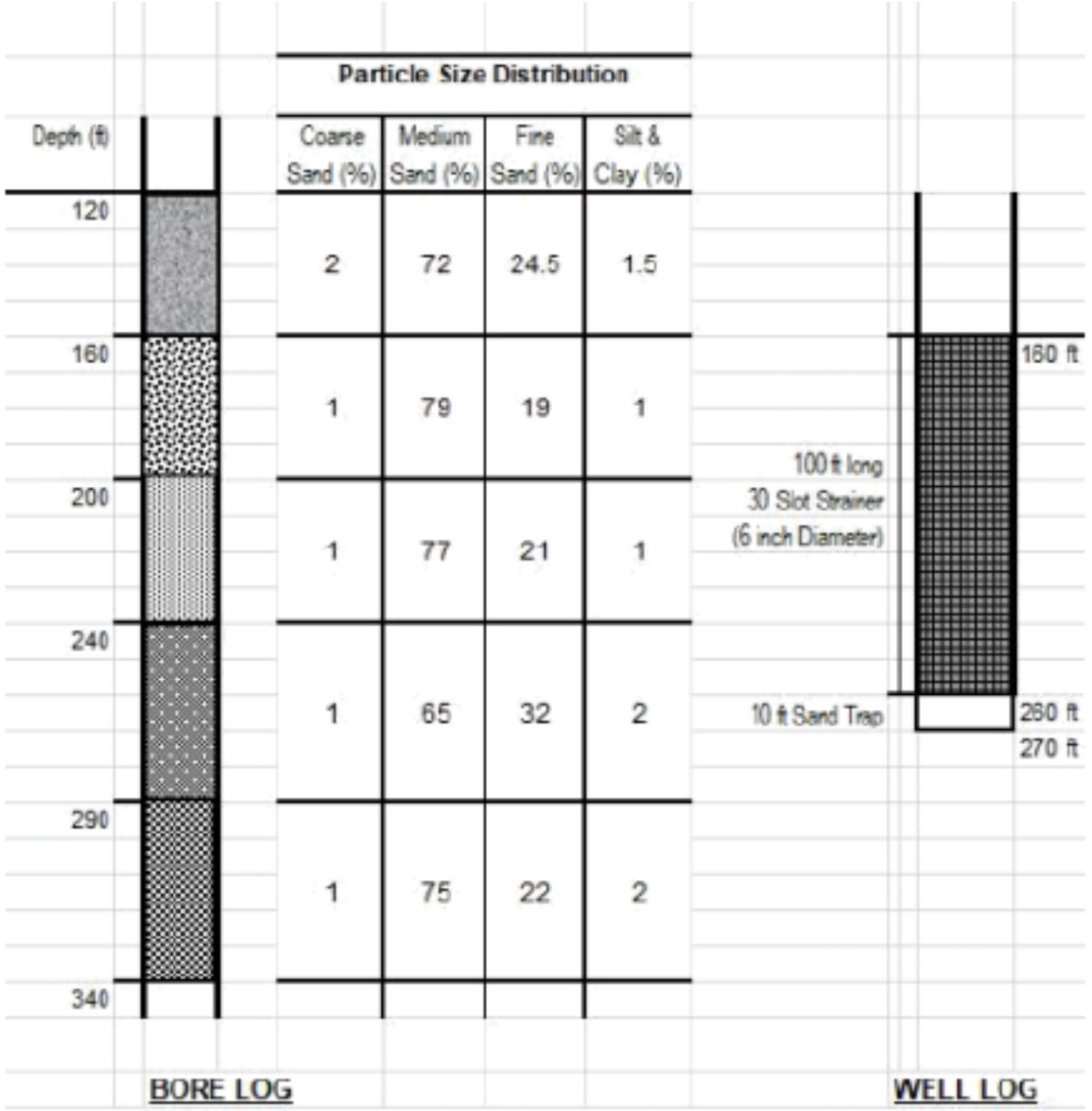
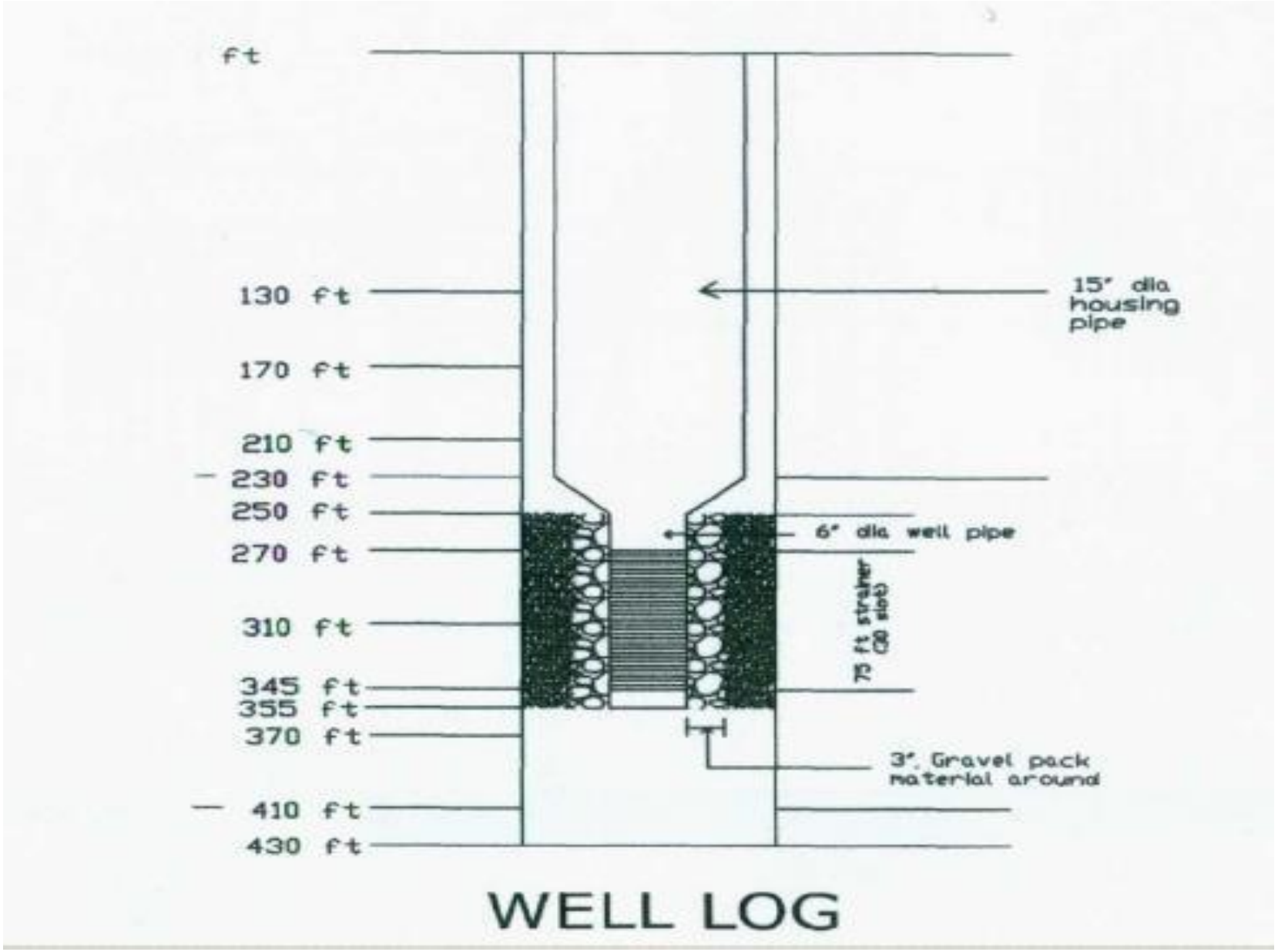



Figure-3: Typical Bore Log and Well Log Presentation

*(NB - this log is not for the tubewell data shown in sample calculation, it is provided as sample format only)*


ft
130 ft
170 ft
210 ft
230 ft
250 ft
270 ft
310 ft
345 ft
355 ft
370 ft
410 ft
430 ft
15" dia housing pipe
6" dia well pipe
75 ft strainer (30 slot)
3". Gravel pack material around

WELL LOG