Dewatering

Outline of Presentation

- **Introduction**
- **Applications**
- **Design**
- **Examples**

Introduction

Purposes for Dewatering

- For construction excavations or permanent structures that are below the water table and are not waterproof or are waterproof but are not designed to resist the hydrostatic pressure
- Permanent dewatering systems are far less commonly used than temporary or construction dewatering systems

Common Dewatering Methods

- Sumps, trenches, and pumps
- Well points
- Deep wells with submersible pumps

Sumps, Trenches, and Pumps

- **Handle minor amount of water inflow**
- **The height of groundwater above the excavation bottom is relatively small (5ft or less)**
- **The surrounding soil is relatively impermeable (such as clayey soil)**

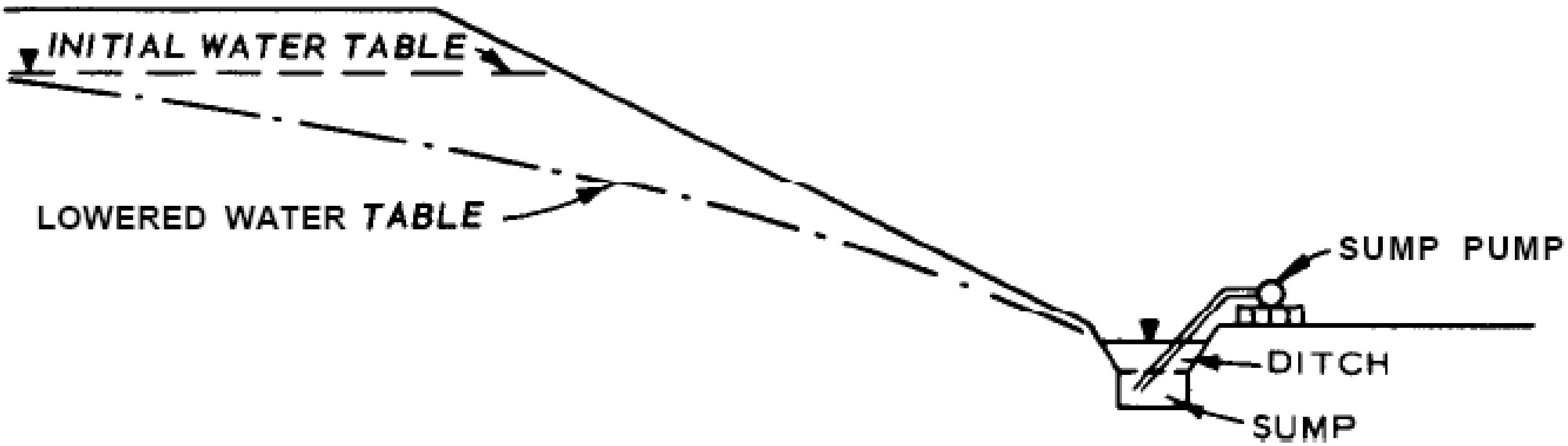
Wet Excavations

- **Sump pumps are frequently used to remove surface water and a small infiltration of groundwater**

- **Sumps and connecting interceptor ditches should be located well outside the footing area and below the bottom of footing so the groundwater is not allowed to disturb the foundation bearing surface**

- **In granular soils, it is important that fine particles no be carried away by pumping. The sump(s) may be lined with a filter material to prevent or minimize loss of fines**

Dewatering Open Excavation by Ditch and Sump



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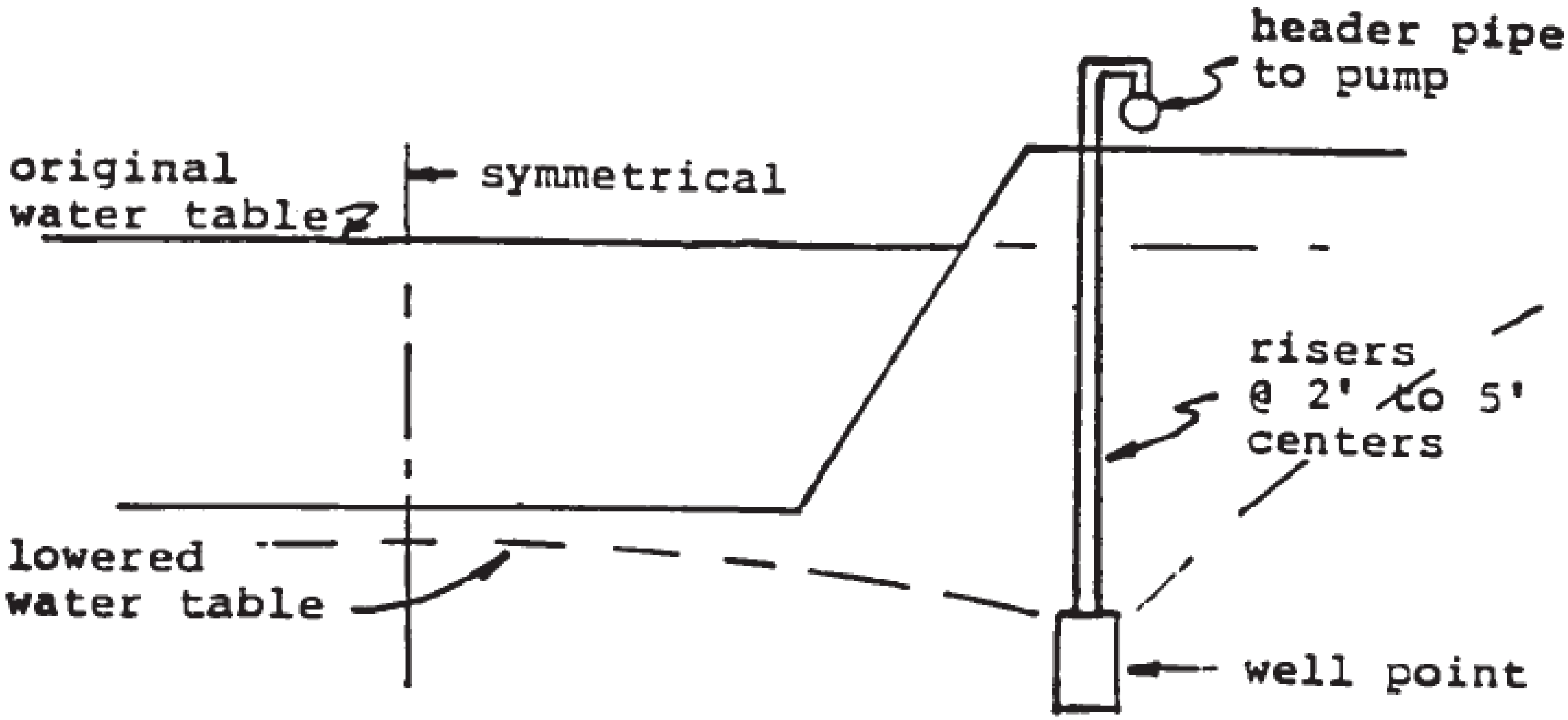
Well Point Method

- Multiple closely spaced wells connected by pipes to a strong pump
- Multiple lines or stages of well points are required for excavations more than 5m below the groundwater table

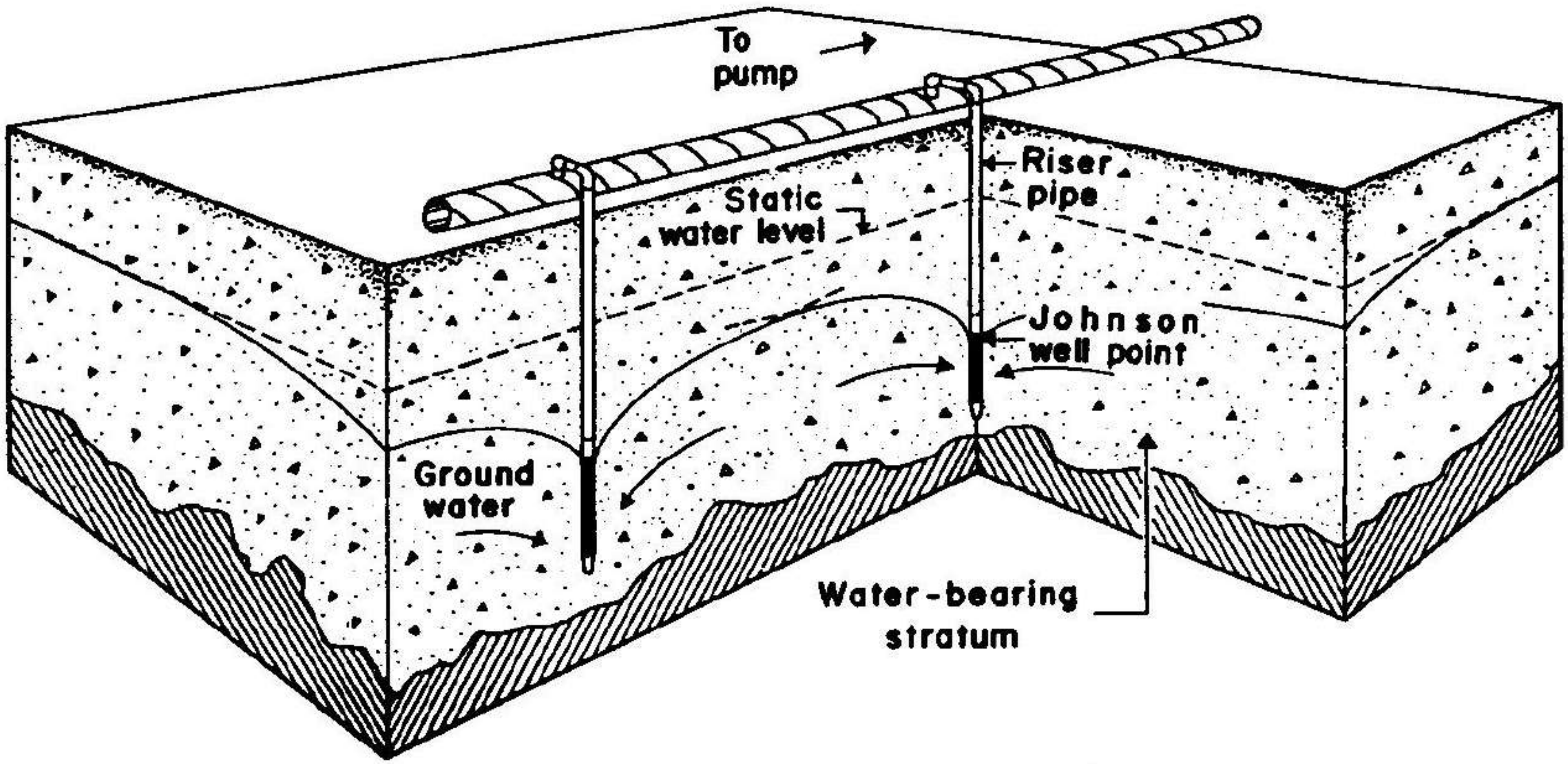
Single Stage Well Point System



Caltrans

Single Stage Well Point System

Typical Well Point System

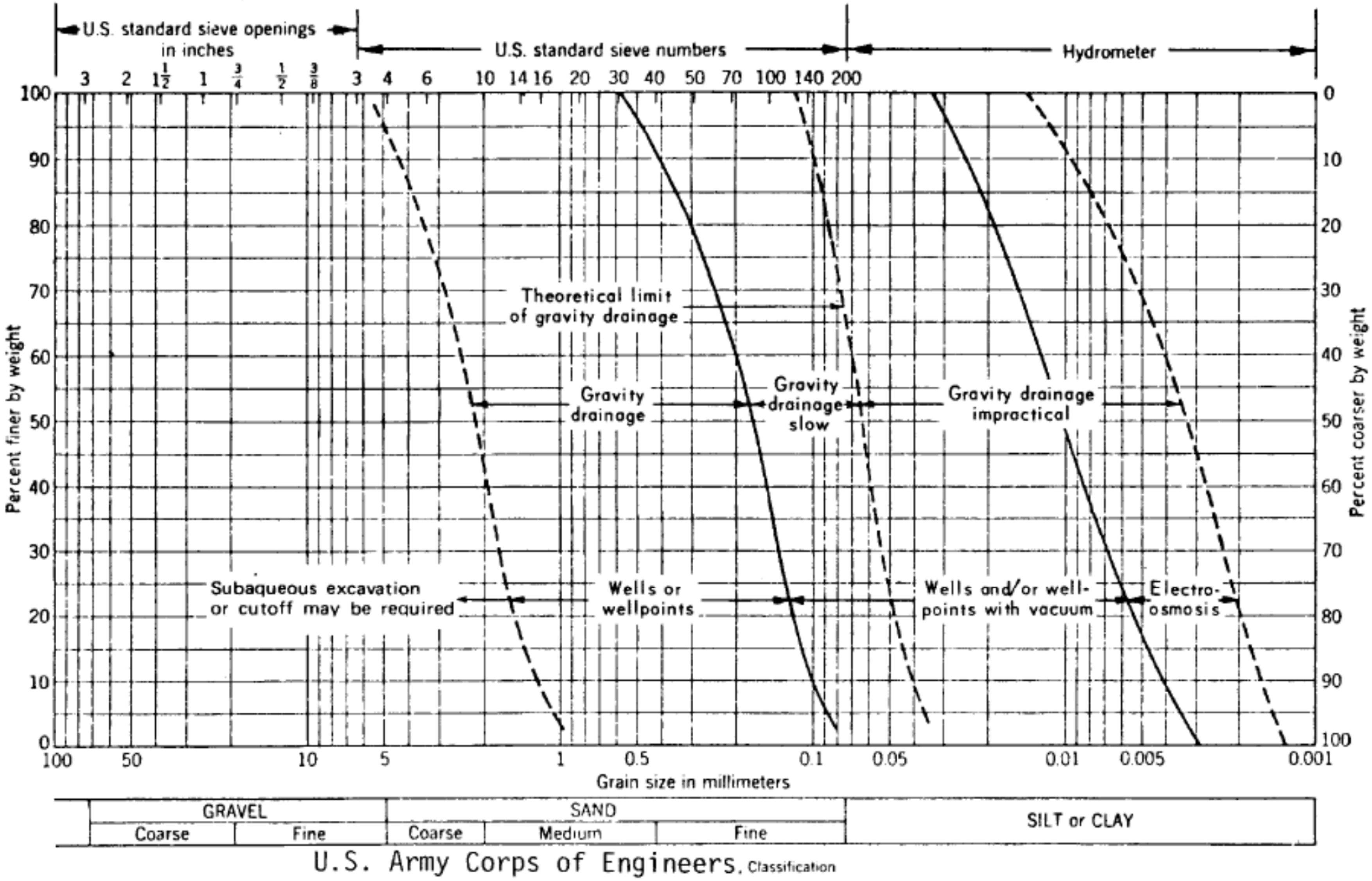


Johnson (1975)

Deep Wells with Submersible Pumps

- Pumps are placed at the bottom of the wells and the water is discharged through a pipe connected to the pump and run up through the well hole to a suitable discharge point
- They are more powerful than well points, require a wider spacing and fewer well holes
- Used alone or in combination of well points

Applicability of Dewatering Systems



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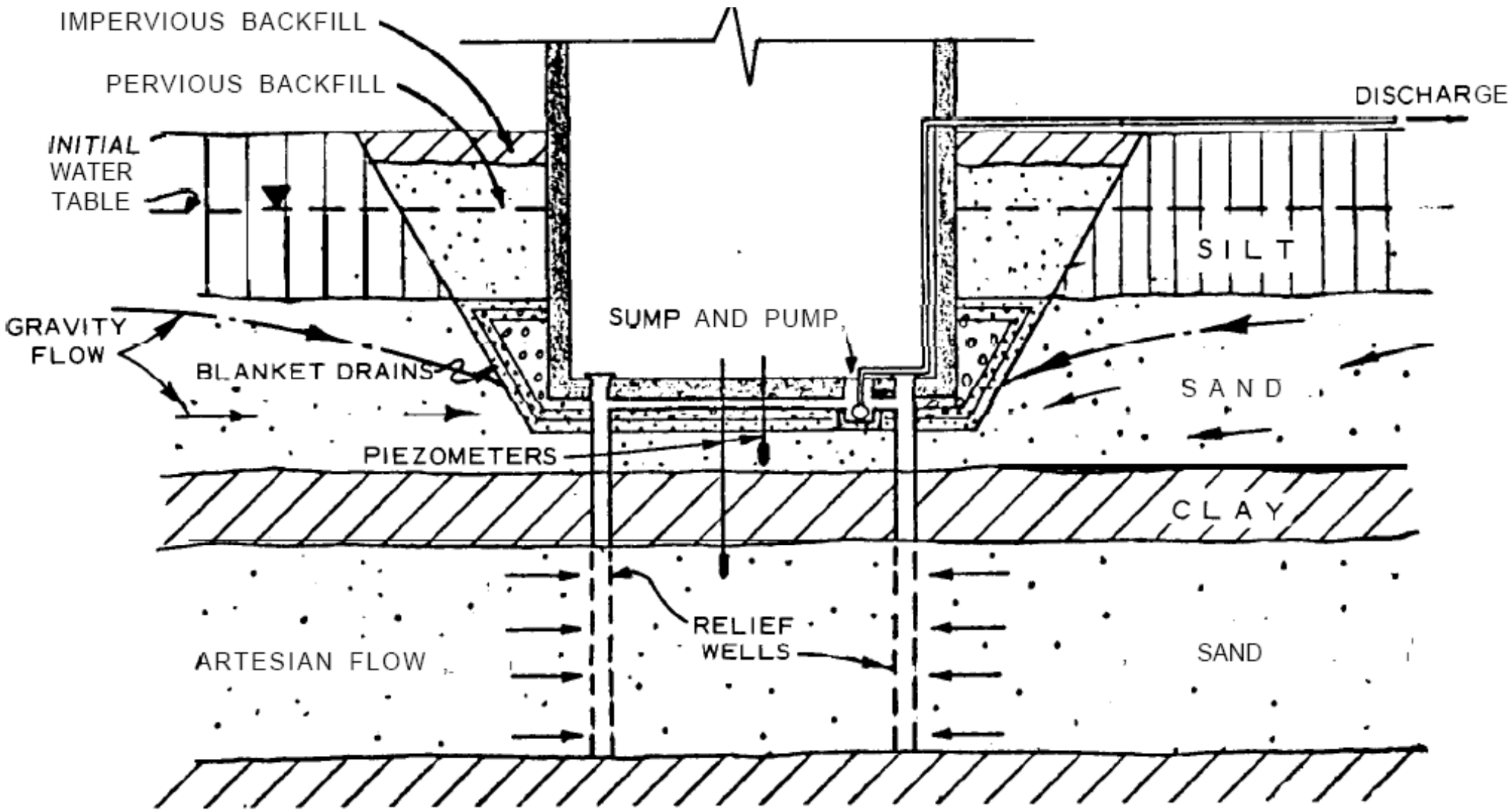
Applications

Permanent Groundwater Control System



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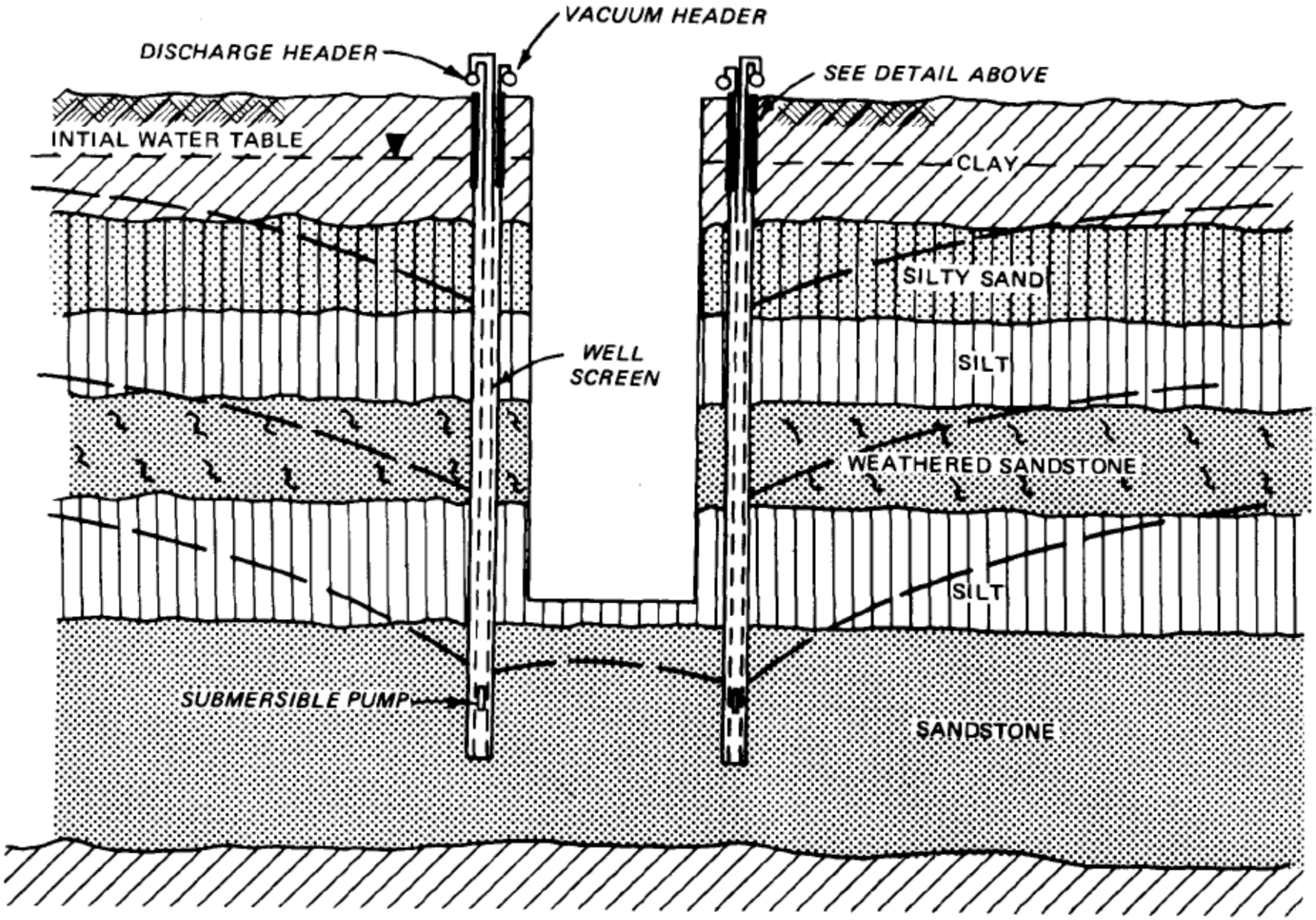
Deep Wells with Auxiliary Vacuum System



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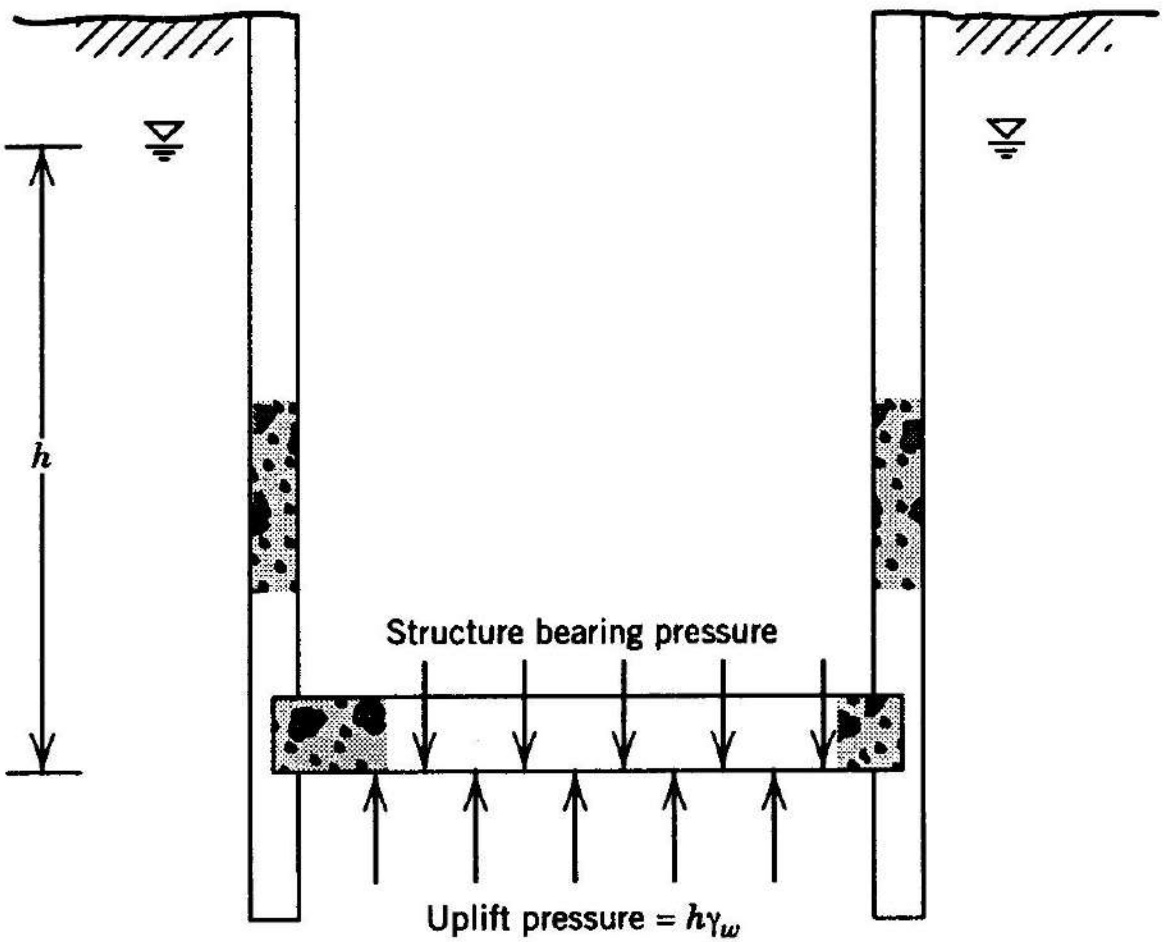
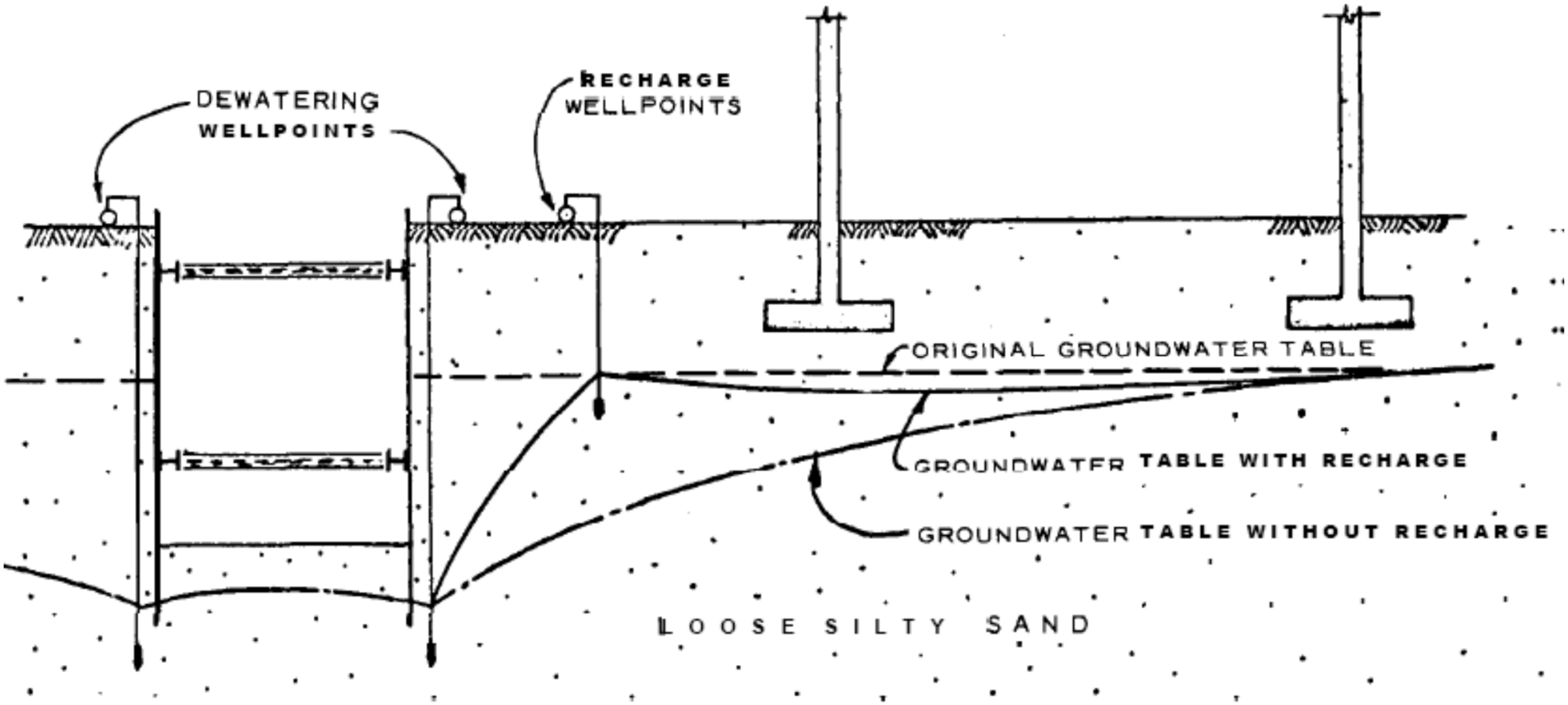
Buoyancy Effects on Underground Structure



Xanthakos et al. (1994)

Recharge Groundwater to Prevent Settlement



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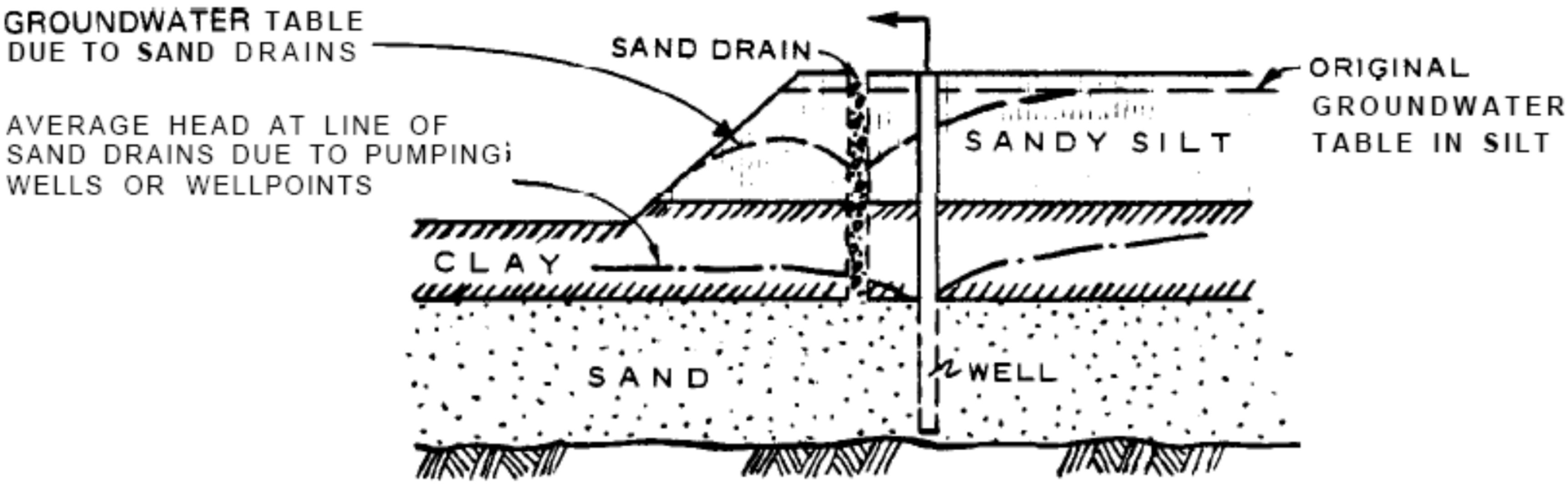
Sand Drains for Dewatering A Slope



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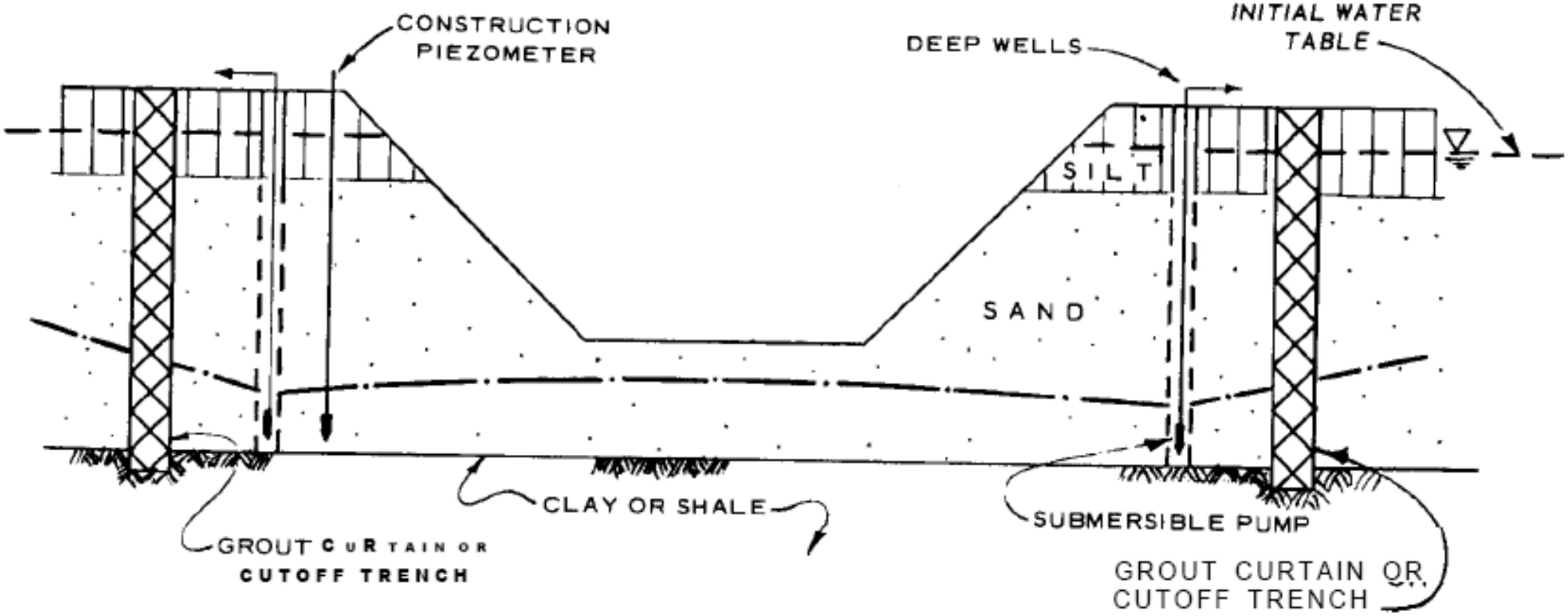
Grout Curtain or Cutoff Trench around An Excavation



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Design

Design Input Parameters

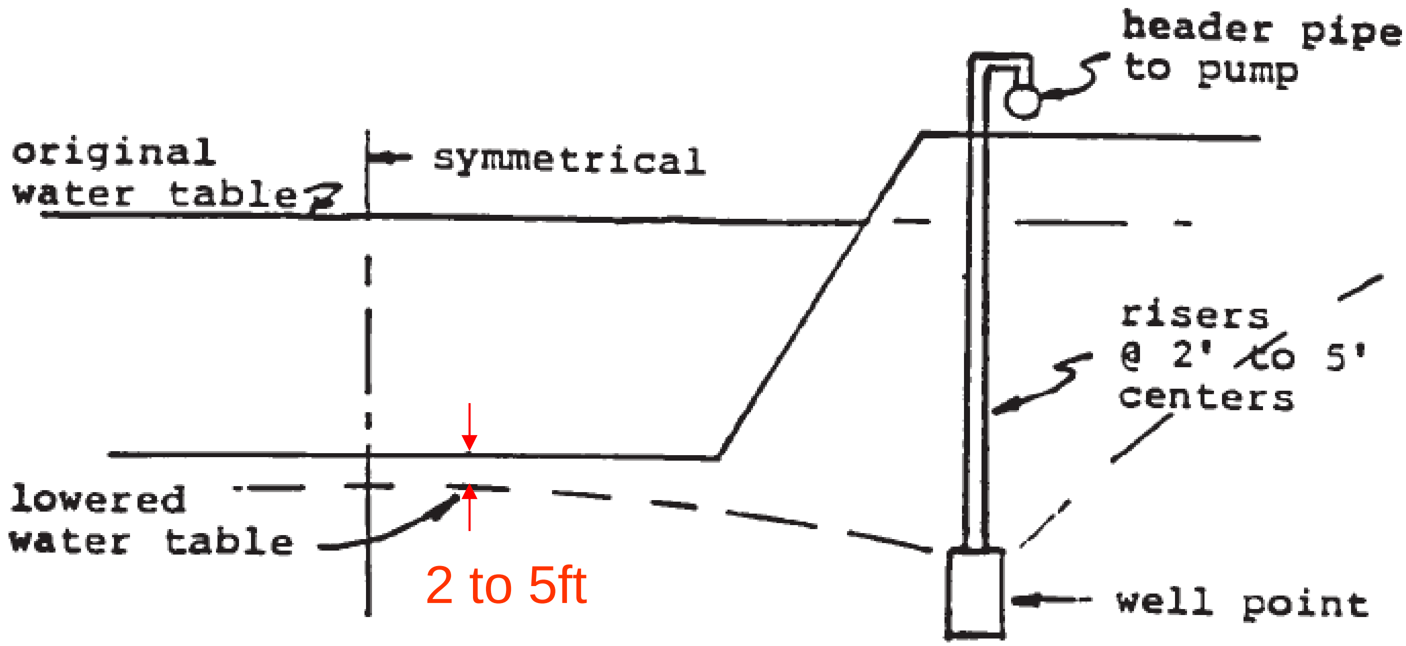
- **Most important input parameters for selecting and designing a dewatering system:**

  - the height of the groundwater above the base of the excavation

  - the permeability of the ground surrounding the excavation

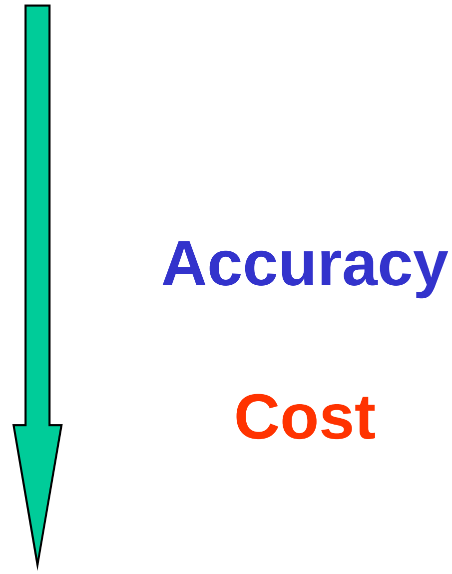
Depth of Required Groundwater Lowering

- **The water level should be lowered to about 2 to 5 ft below the base of the excavation**



Methods for Permeability

- Empirical formulas
- Laboratory permeability tests
- Borehole packer tests
- Field pump tests



Darcy's Law

Average velocity of flow

$$v = ki = k\frac{h}{L}$$

Actual velocity of flow

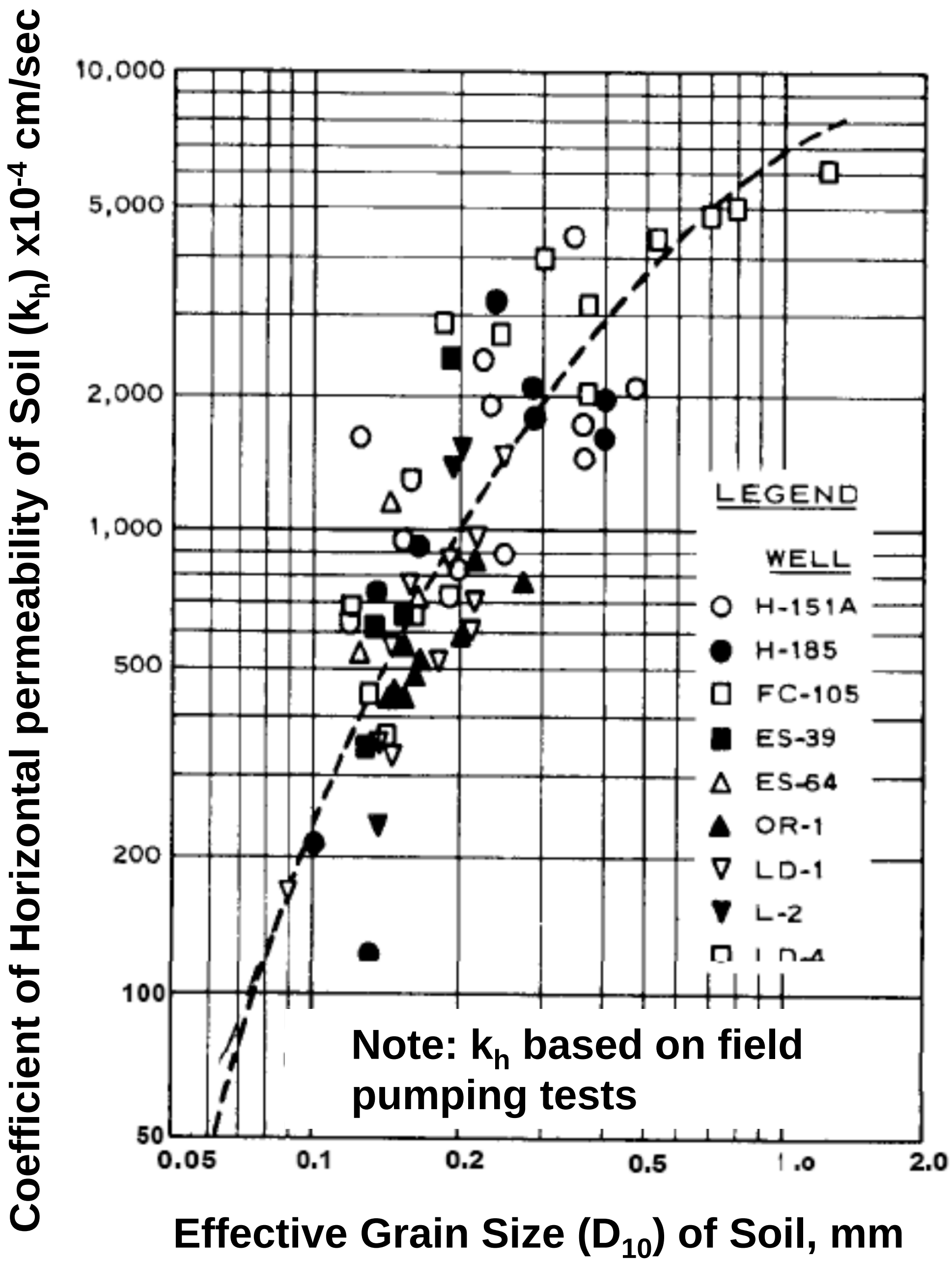
$$v_a = \frac{v}{n}$$

Rate (quantity) of flow

$$q = kiA = k\frac{h}{L}A$$

Typical Permeability of Soils

Soil or rock formation	Range of k (cm/s)
Gravel	1 - 5
Clean sand	10^{-3} - 10^{-2}
Clean sand and gravel mixtures	10^{-3} - 10^{-1}
Medium to coarse sand	10^{-2} - 10^{-1}
Very fine to fine sand	10^{-4} - 10^{-3}
Silty sand	10^{-5} - 10^{-2}
Homogeneous clays	10^{-9} - 10^{-7}
Shale	10^{-11} - 10^{-7}
Sandstone	10^{-8} - 10^{-4}
Limestone	10^{-7} - 10^{-4}
Fractured rocks	10^{-6} - 10^{-2}



Permeability vs. Effective Grain Size

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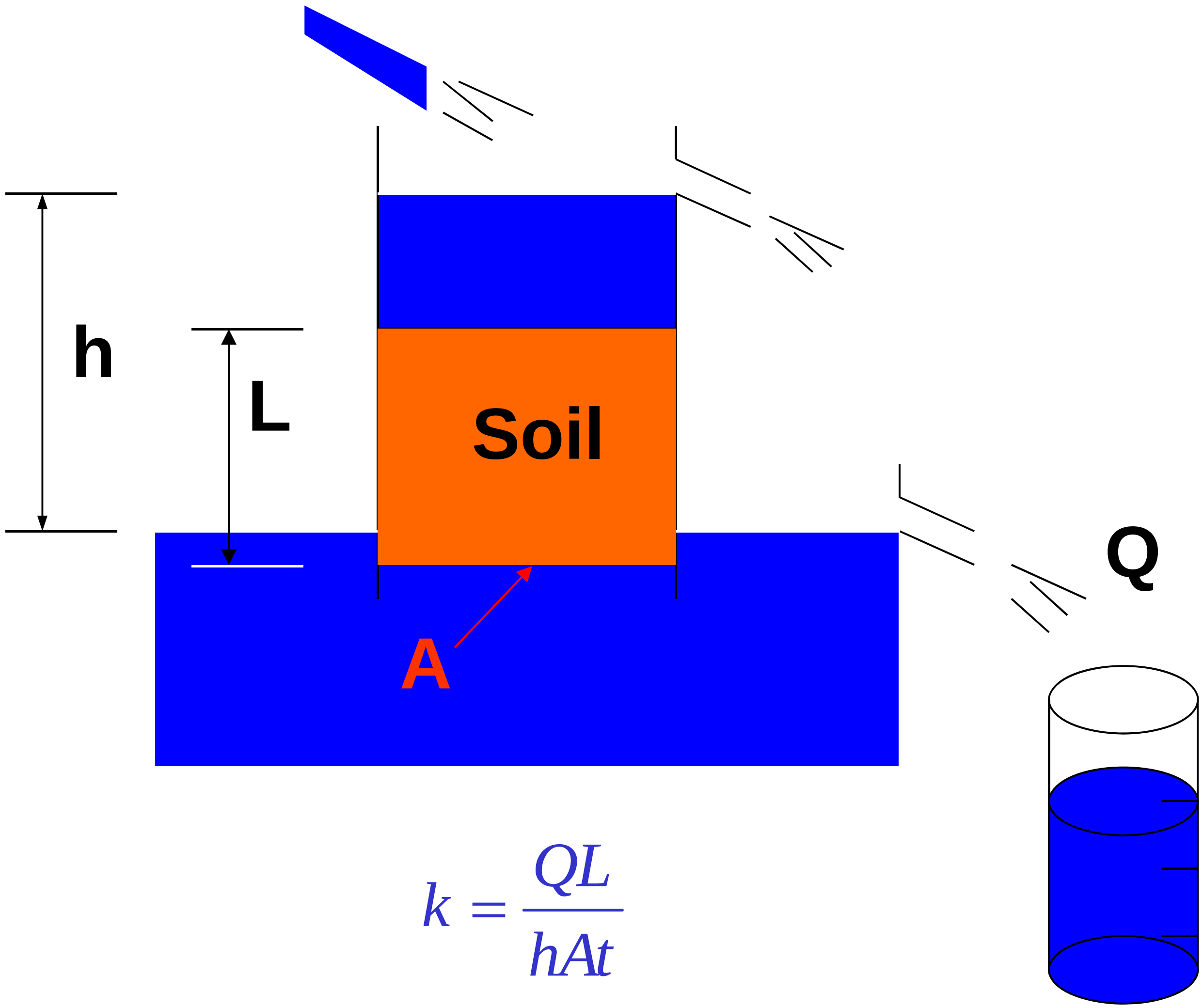
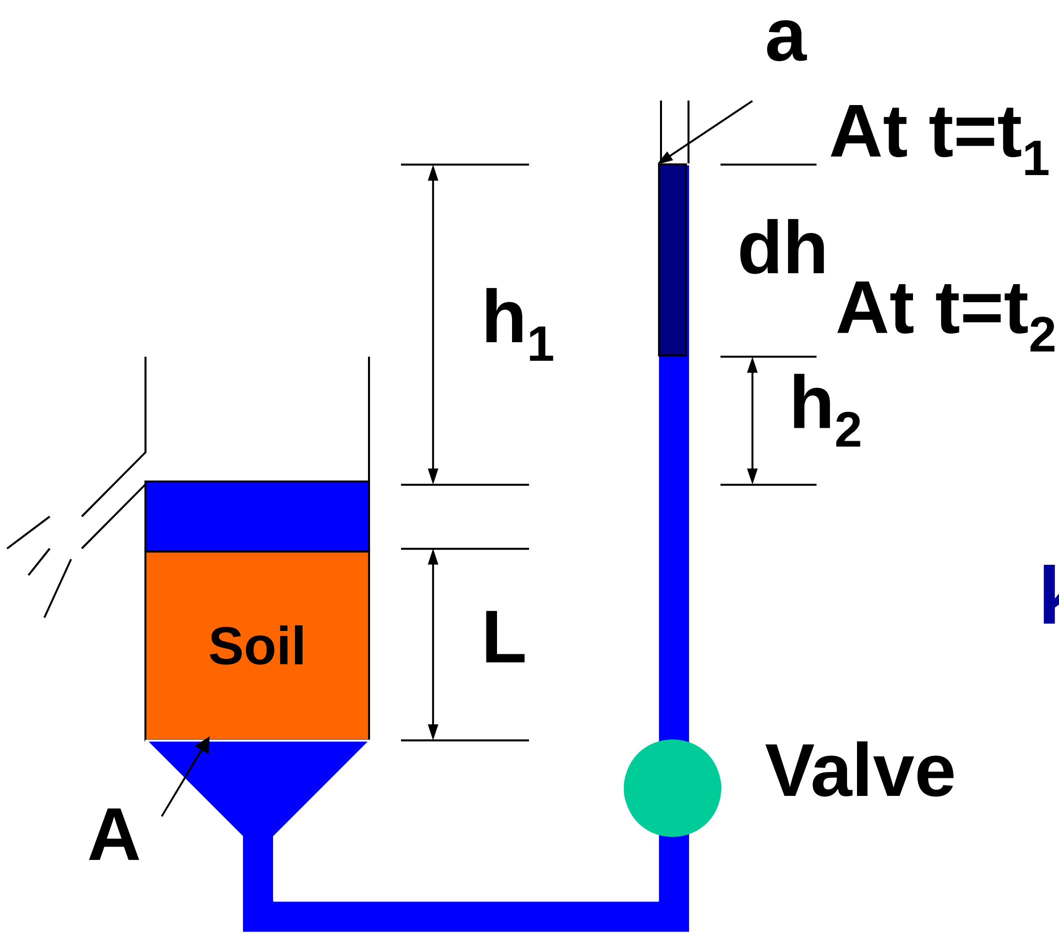
Constant Head Test



$$k = \frac{QL}{hAt}$$

Falling Head Test



$$k = \frac{aL}{A\Delta t}\ln\left(\frac{h_1}{h_2}\right)$$

Laboratory Test Methods

Rigid wall test

- AASHTO T215; ASTM D 2434
- Typically for sandy & granular soils (k > 10^{-3} cm/s)
- Not recommended for low permeability soils (k < 10^{-6} cm/s)

Flexible wall test

- ASTM D 5084
- Typically for soils (k $\leq$ 10^{-3} cm/sec)

Flexible vs. Rigid Wall

- In rigid walled permeameters
  - Simpler apparatus
  - Leakage along side-wall possible, especially if sample shrinks
  - May use double ring equipment to discount side-wall leakage
- In flexible walled permeameters (triaxial cells)
  - No side leakage
  - Effective stress (hence k) varies

Rigid Wall Permeameter

Shelby Tube Permeameter

- **Device designed to use a 6-in section of a standard 3-in diameter Shelby tube**

- **Ideal for testing loose sands and other materials**

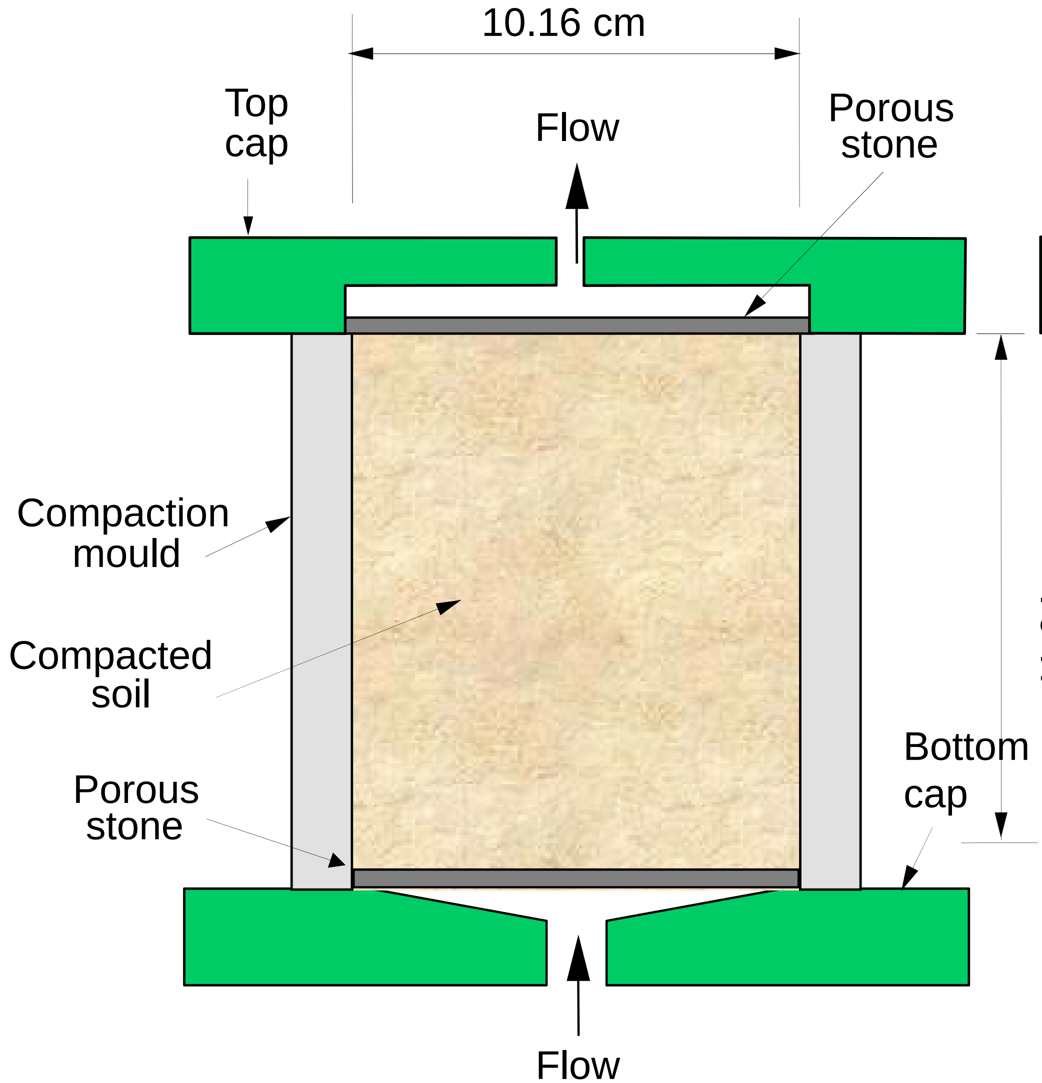
(Durham Geo Slope Indicator)

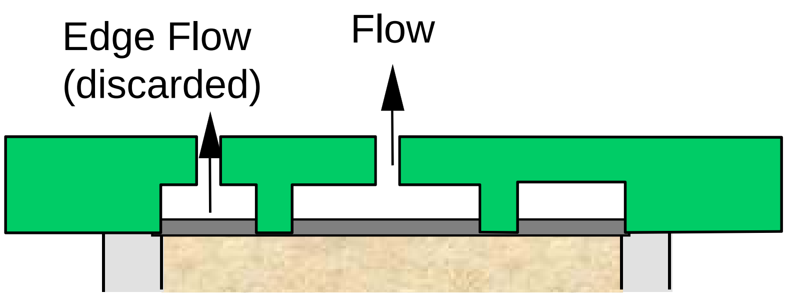
Compaction Permeameter

- **uses standard 4 in and 6 in compaction molds for falling or constant head permeability tests**

(Durham Geo Slope Indicator)

Rigid Wall Permeameter





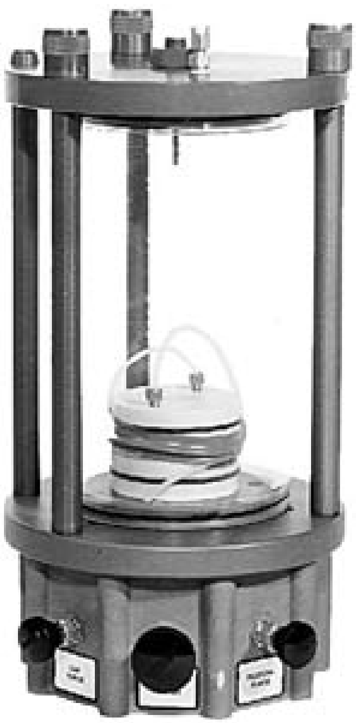
- Double ring permeameter introduced to measure k without including side-wall leakage which would lead to high estimates of k

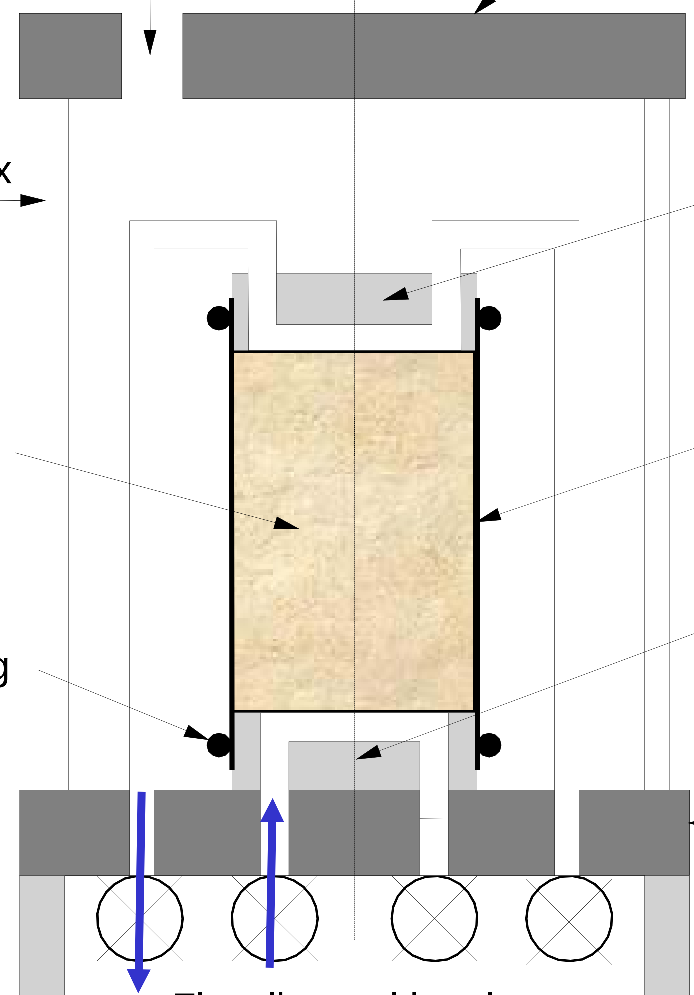
Double Ring Permeameter

- A standard 4 in compaction mold
- A stainless steel sleeve in the base divides the sample into two equal portions, allowing measurement of the permeant flow from the center and perimeter of the sample concurrently
- Flow is monitored with two 5 ml pipettes

(Durham Geo Slope Indicator)

Flexible Wall Permeameter





- Different σ’ at top and bottom of specimen

Flexible Wall Permeameter

Permeability Testing

- Usually test soils with very low permeability coefficient (<10^{-9} m/s??)

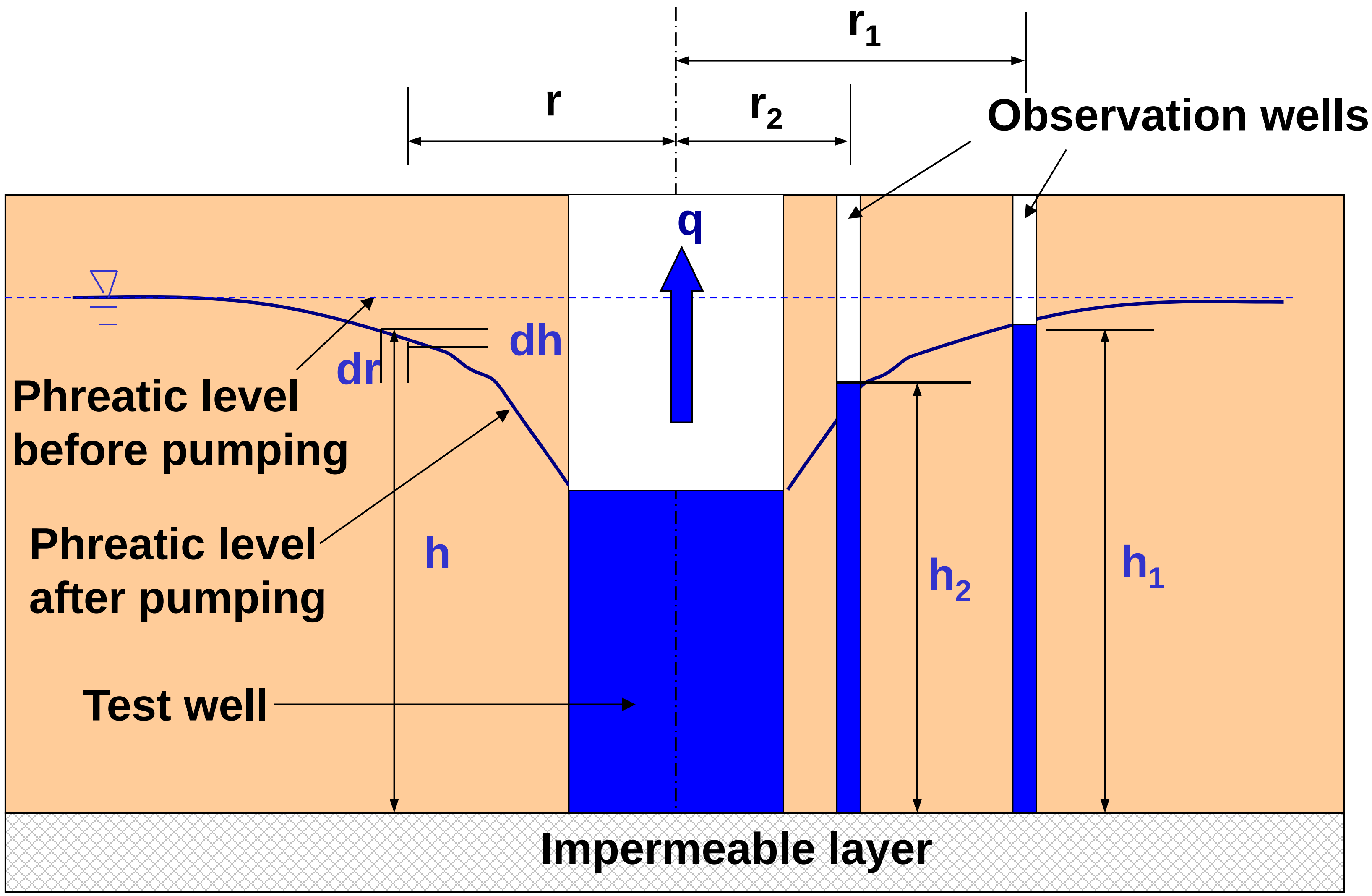
$$v = -ki = -k\frac{dh}{dl}$$

- To make testing practical, increase i
- But high i may cause
  - cracking in soil
  - unrepresentative flow regime (Darcy not true anymore)
  - internal erosion
  - edge leakage in test apparatus

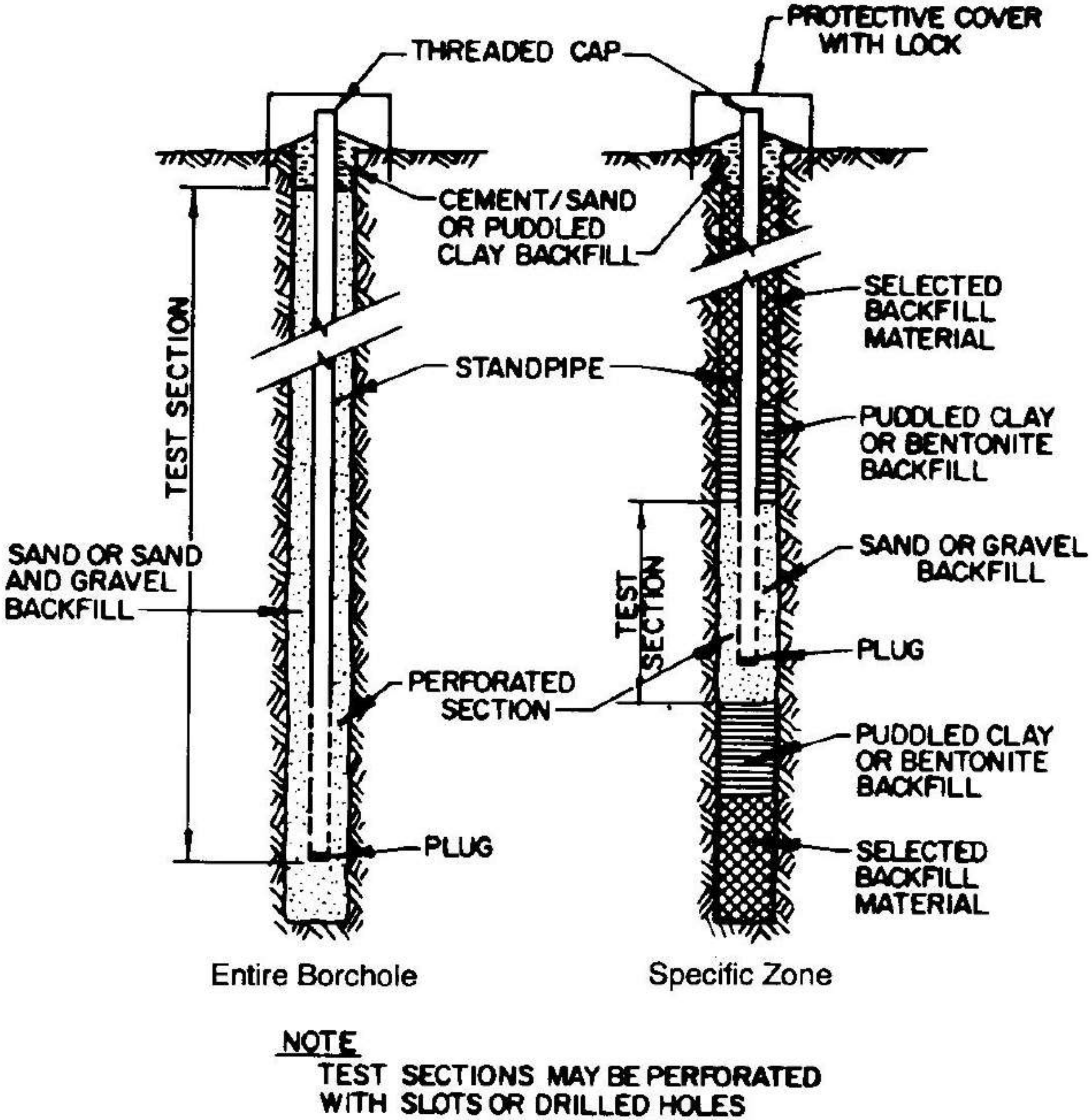
Recommended Maximum Hydraulic Gradient

k (cm/sec)	i_{max}
$1x10^{-3} – 1x10^{-4}$	2
$1x10^{-4} – 1x10^{-5}$	5
$1x10^{-5} – 1x10^{-6}$	10
$1x10^{-6} – 1x10^{-7}$	20
$< 1x10^{-7}$	30

Field Pumping Test



Observation Wells



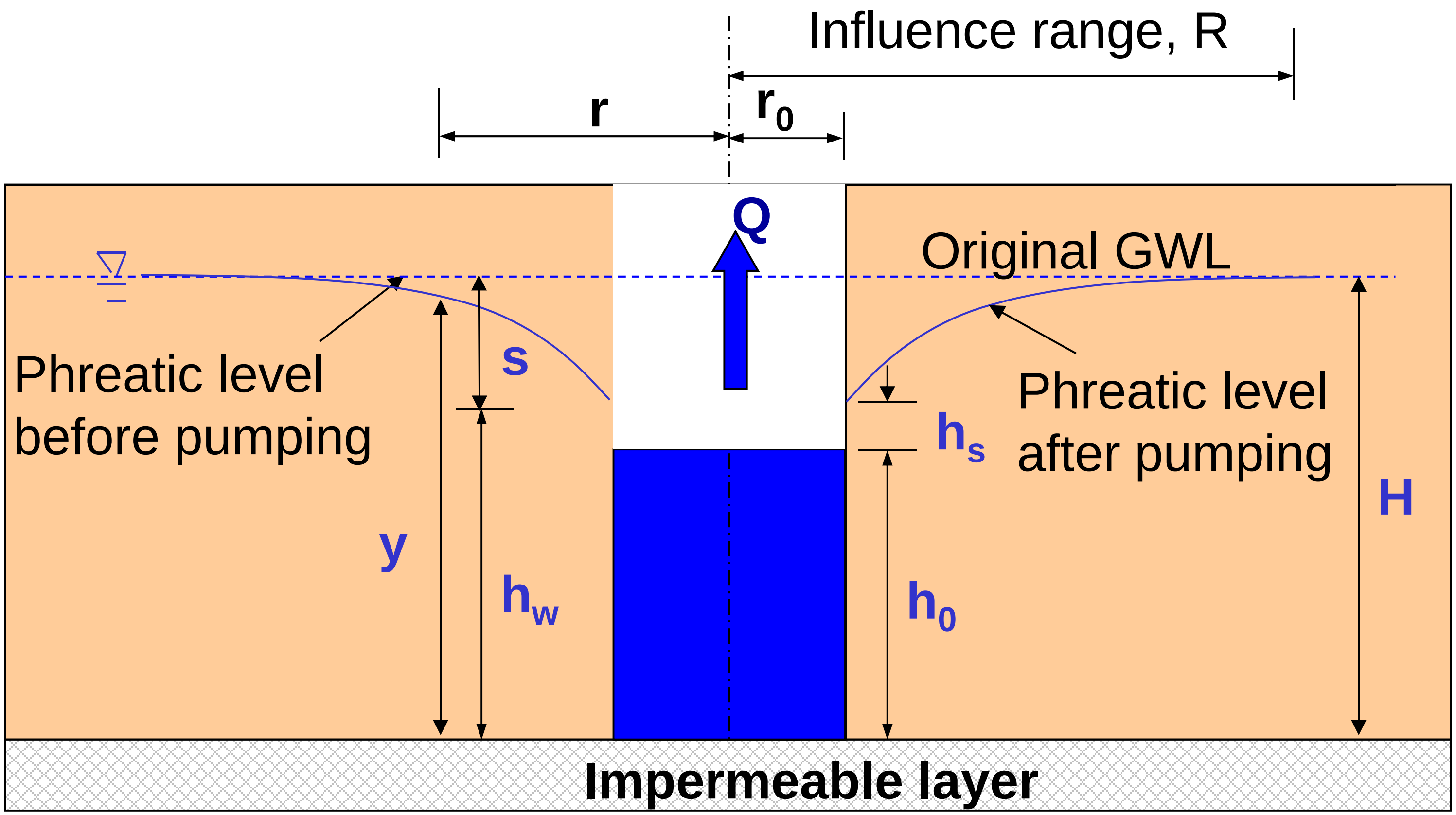
NAVFAC (1982)

Permeability from Field Pumping Test

Permeability

$$\mathbf{k} = \frac{\mathbf{q} \ln\left(\mathbf{r_1}/\mathbf{r_2}\right)}{\pi\left(\mathbf{h_1^2} - \mathbf{h_2^2}\right)}$$

Dupuit-Thiem Approximation for Single Well



$$Q = \frac{\pi k\left(H^2 - h_w^2\right)}{\ln\left(R/r_0\right)} = 1.366k\frac{\left(H^2 - h_w^2\right)}{\log\left(R/r_0\right)}$$

$$y^2 - h_w^2 = \frac{Q\ln\left(r/r_0\right)}{\pi k}$$

Height of Free Discharge Surface

$$h_s = \frac{C(H - h_0)}{H}$$

Ollos proposed a value of C = 0.5

Influence Range

Sichardt (1928)

$$R = C'(H - h_w)\sqrt{k}$$

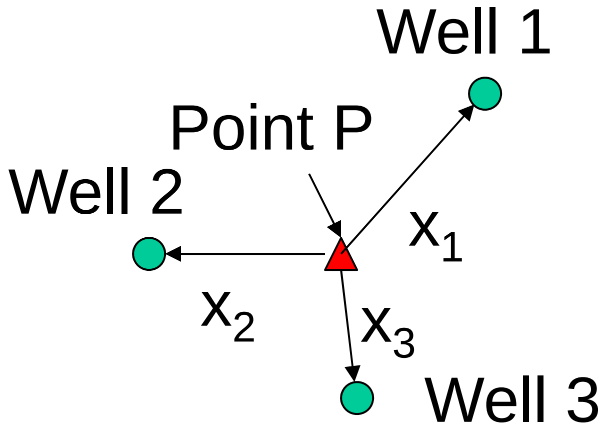
C = 3000 for wells
or 1500 to 2000 for single line well points

H, h_w in meters and k in m/s

Forchheimer Equation for Multiwells

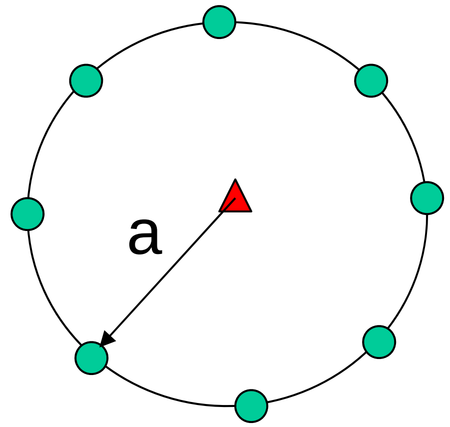
Forchheimer (1930)

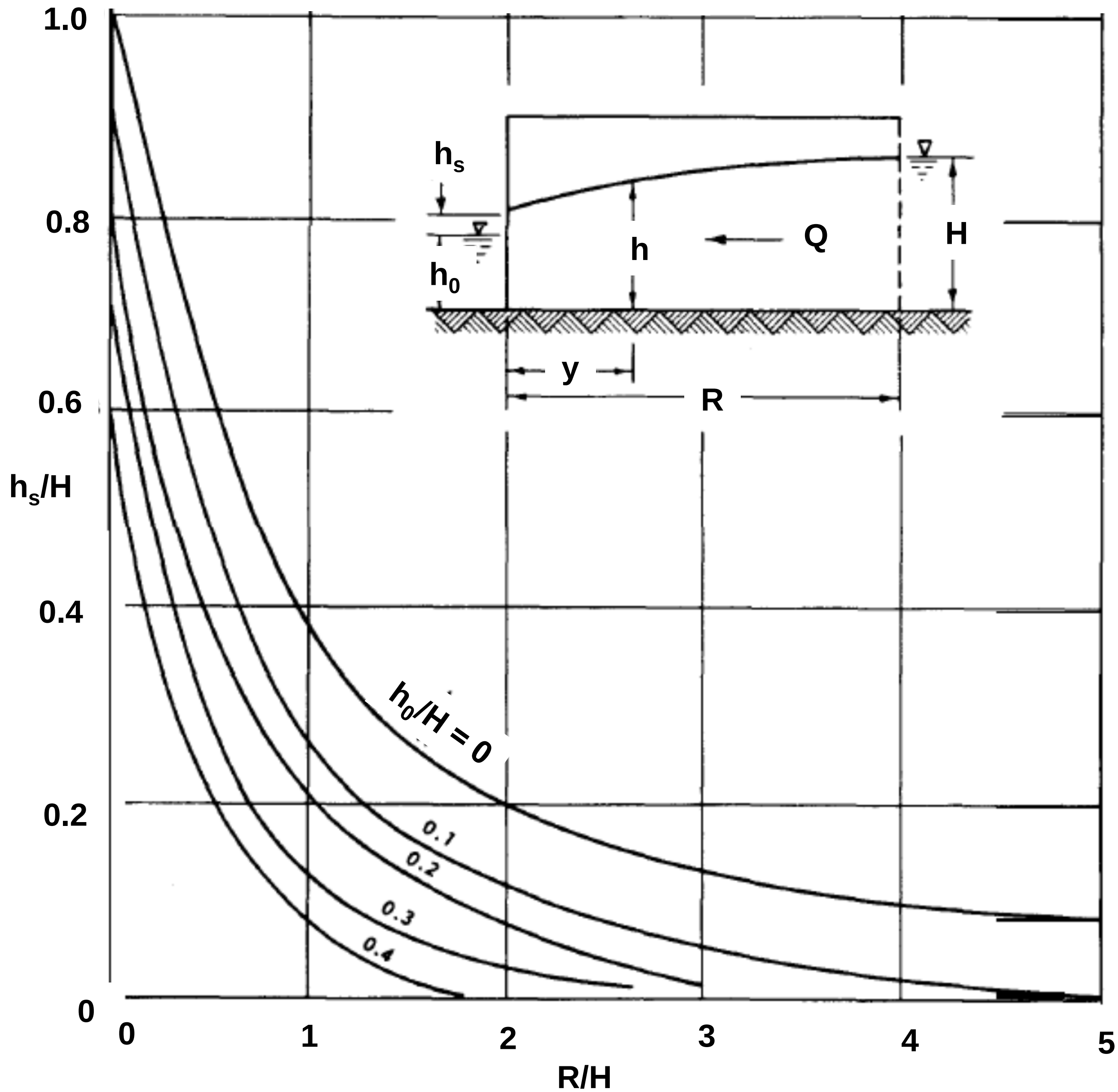
$$Q = \frac{\pi k \left(H^2 - y^2\right)}{\ln R - (1/n)\ln x_1 x_2 \ldots x_n}$$



Circular arrangement of wells

$$Q = \frac{\pi k \left(H^2 - y^2\right)}{\ln R - \ln a}$$





Height of Free Discharge Surface

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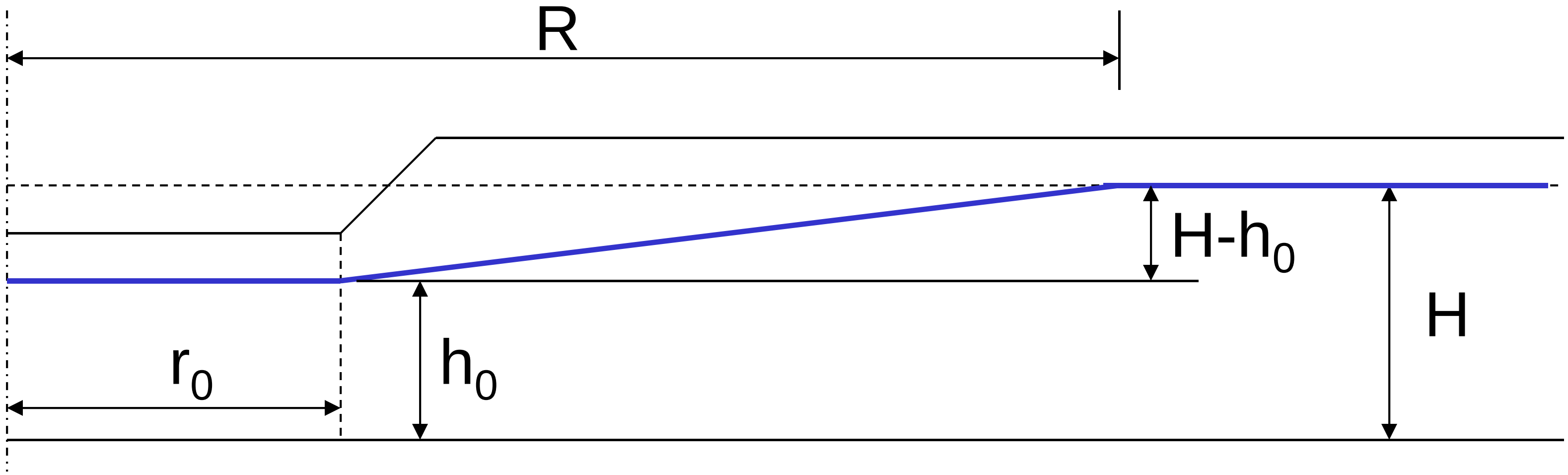
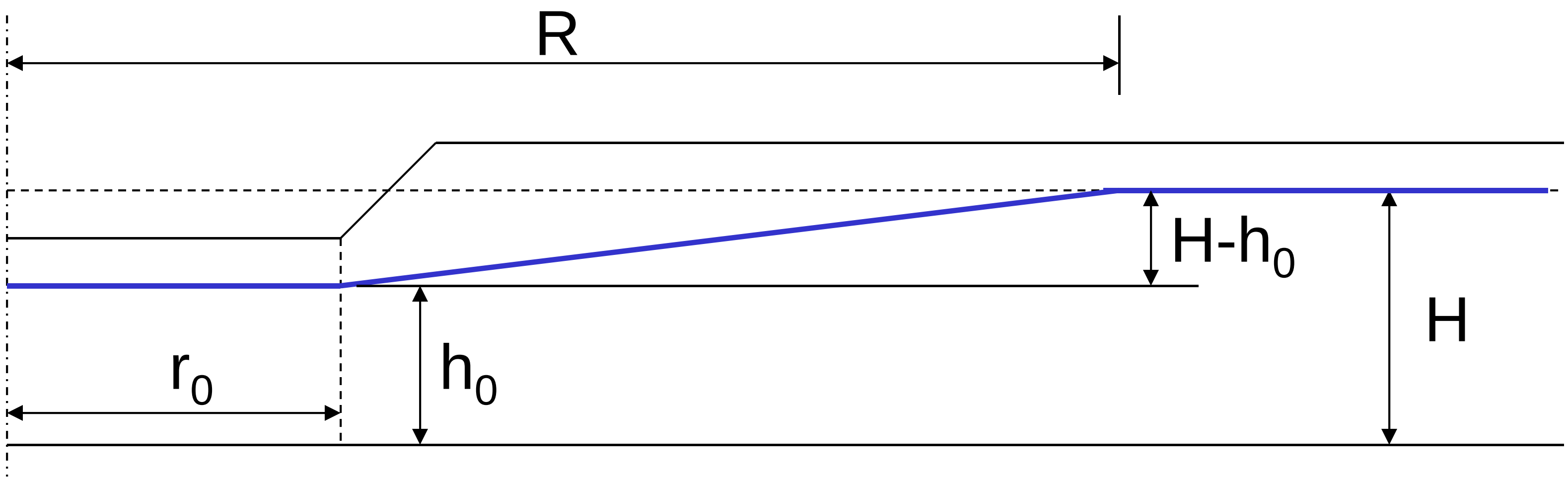
Estimation of Flow Rate – Darcy's Law



$$Q = 1.571k\frac{(H - h_0)(H + h_0)(R + r_0)}{R - r_0}$$

Cedergren (1967)

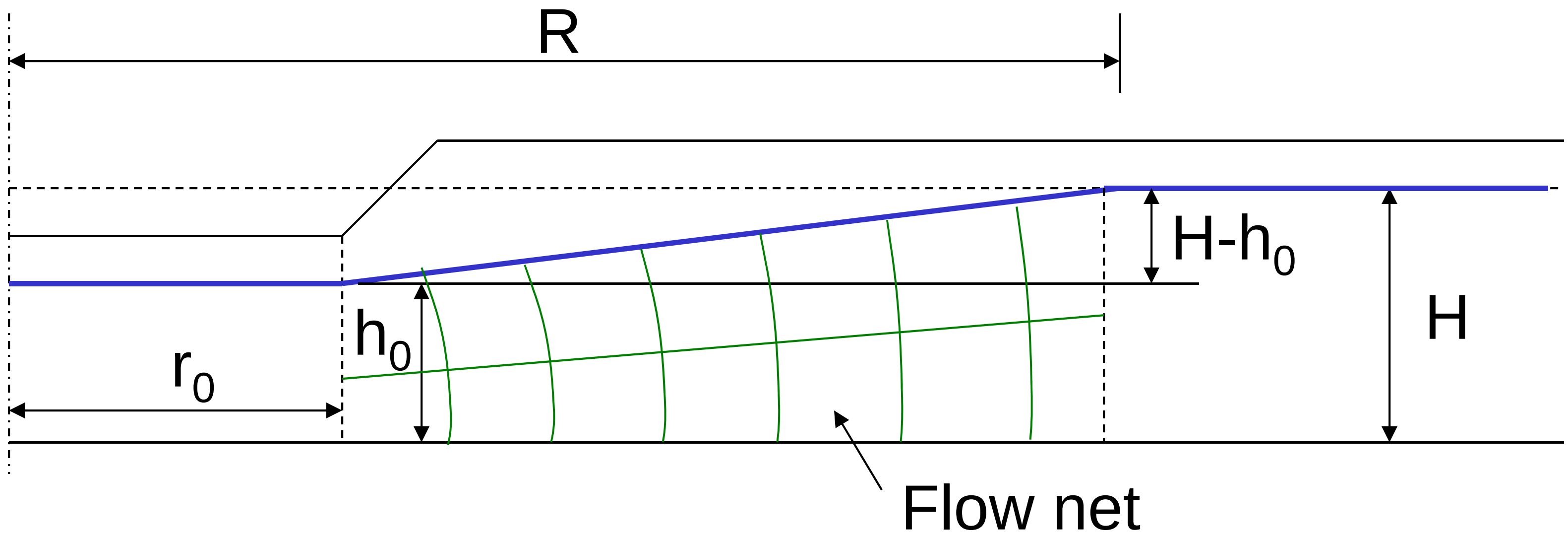
Estimation of Flow Rate – Well Formulas



$$Q = 1.366k\frac{H^2 - h_0^2}{\log(R/r_0)}$$

Cedergren (1967)

Estimation of Flow Rate – Flow Nets



$$Q = 3.14k(H - h_0)(R + r_0)\frac{n_f}{n_d}$$

n_f = number of flow channels

n_d = number of head drops

Cedergren (1967)

Capacities of Common Deep Well Pumps

Min. i.d. of well pump can enter (in.)	Preferred min. i.d. of well (in.)	Approximate max. capacity (gal/min)
4	5	90
5 5/8	6	160
6	8	450
8	10	600
10	12	1,200
12	14	1,800
14	16	2,400
16	18	3,000

Mansur and Kaufman (1962)

Rate of Flow into A Pumped Well or Well Point

Approximate formula

$$Q = 44\sqrt{k}\, r_w h_0$$

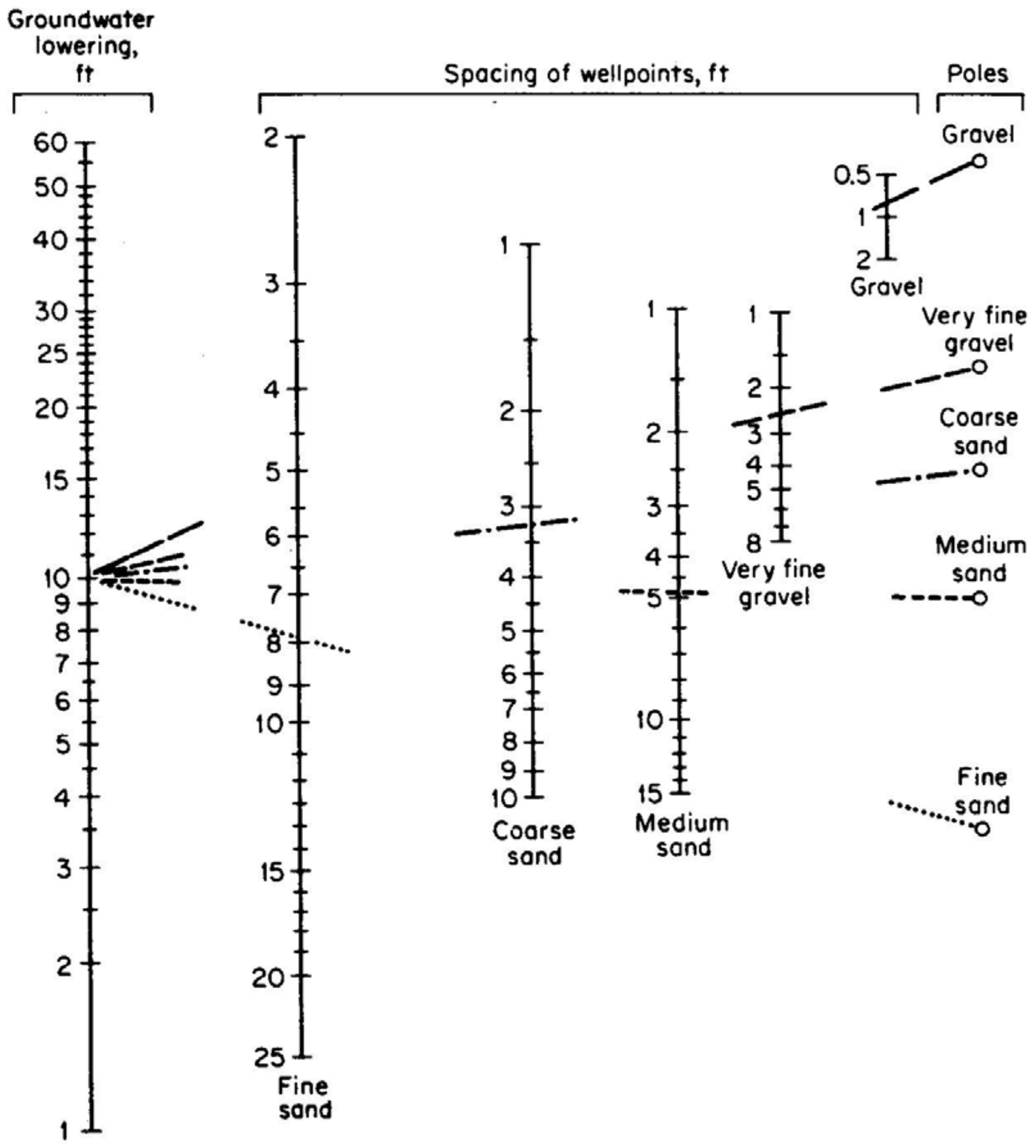
k = permeability, ft/min

r_w = effective radius of the well, ft

h_0 = depth of immersion of well, ft

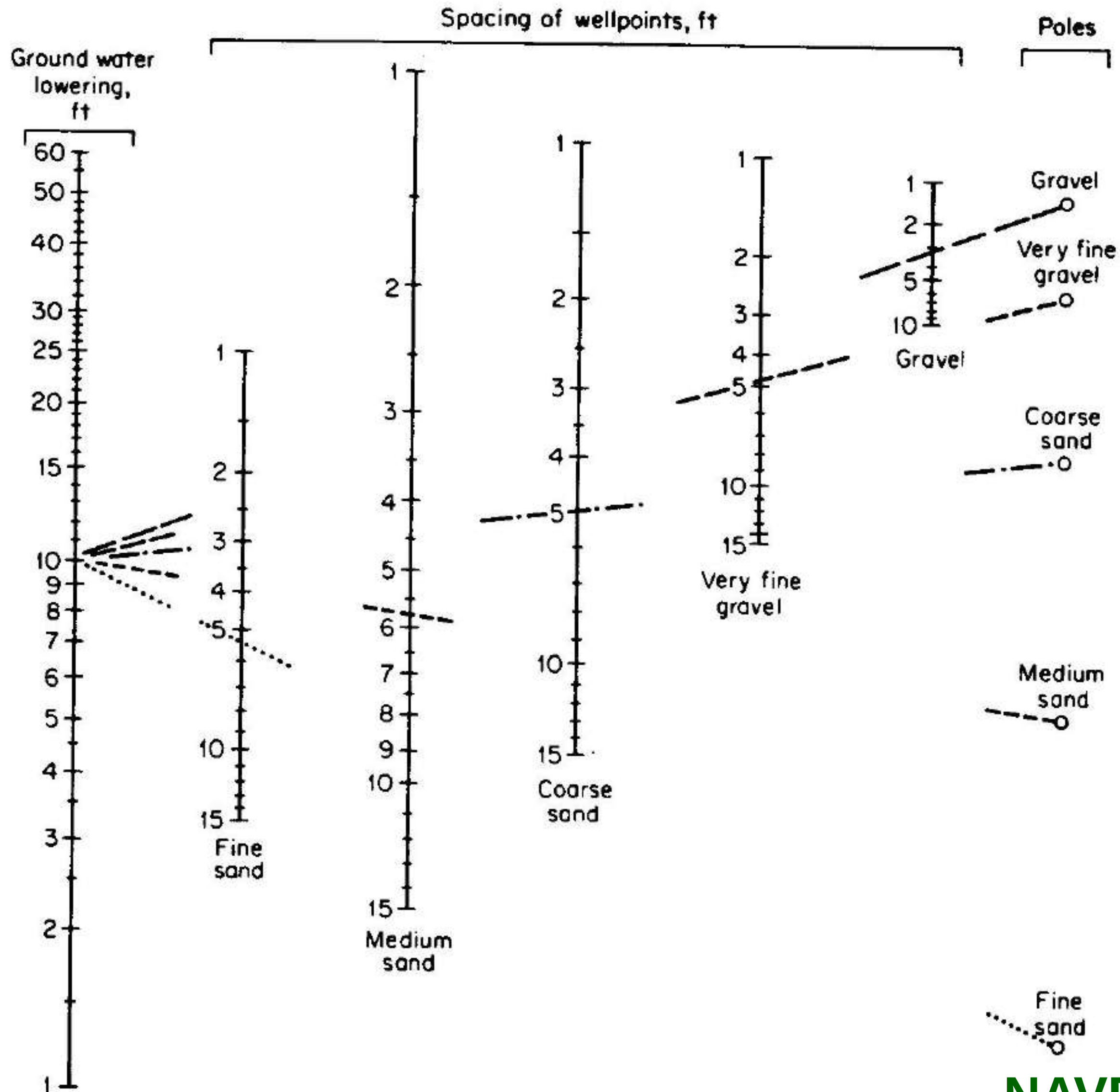
Bush (1971)

Typical Well Point Spacing in Granular Soils



NAVFAC (1982)

Typical Well Point Spacing in Stratified Soils

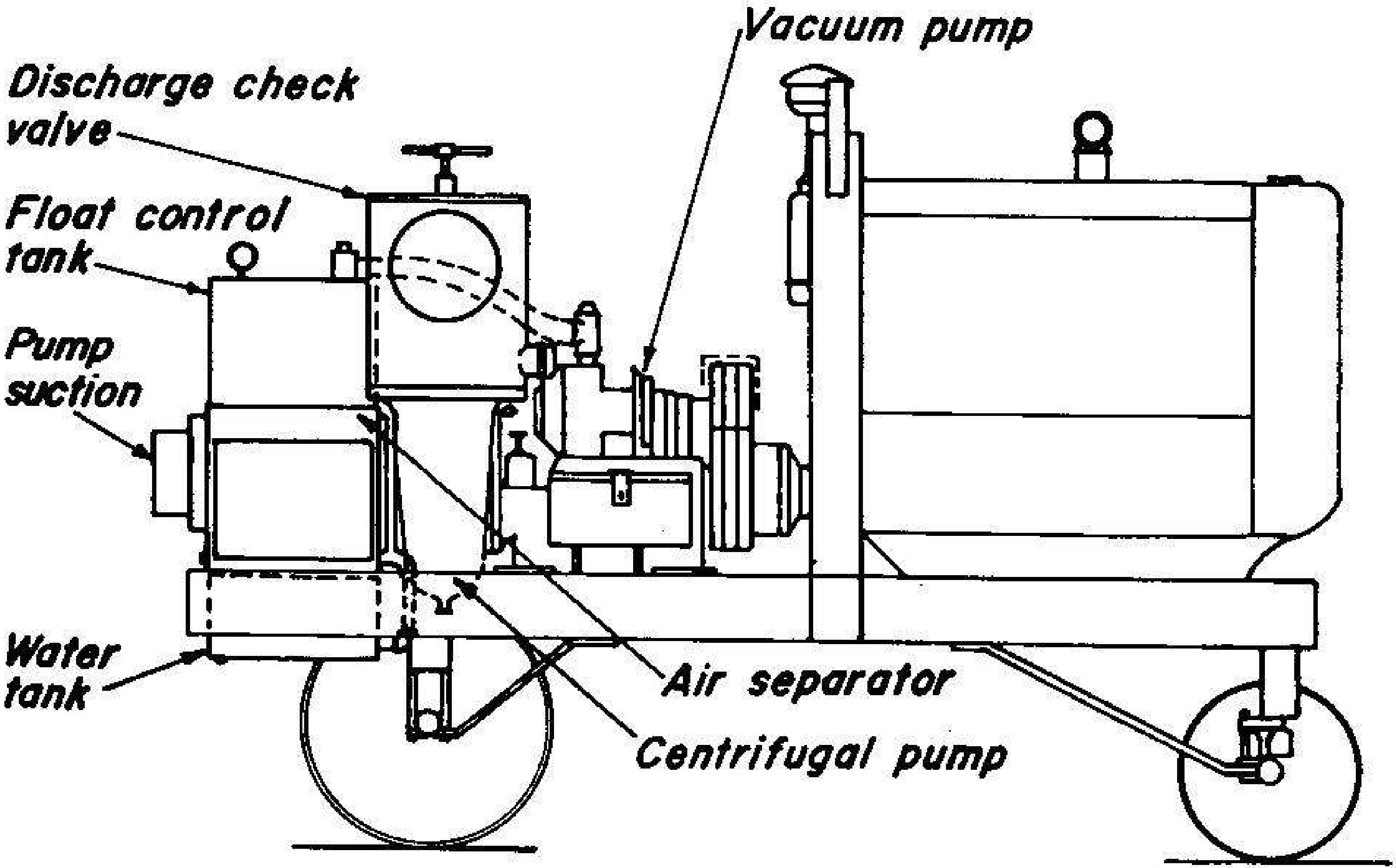


NAVFAC (1982)

Spacing of Deep Wells

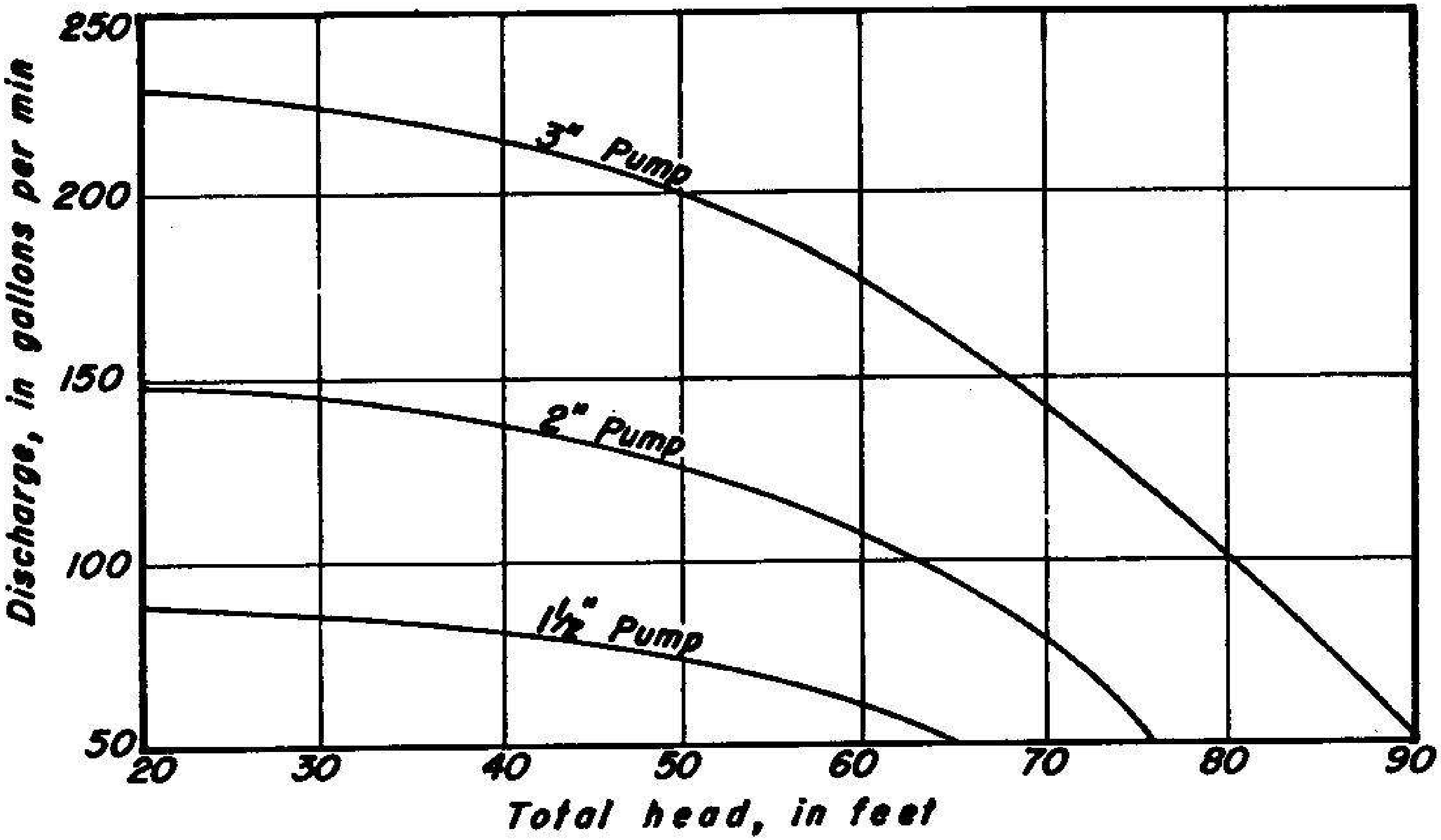
- The spacing of deep wells required equals the perimeter of the excavation divided by the number of wells required

Well Point Pump



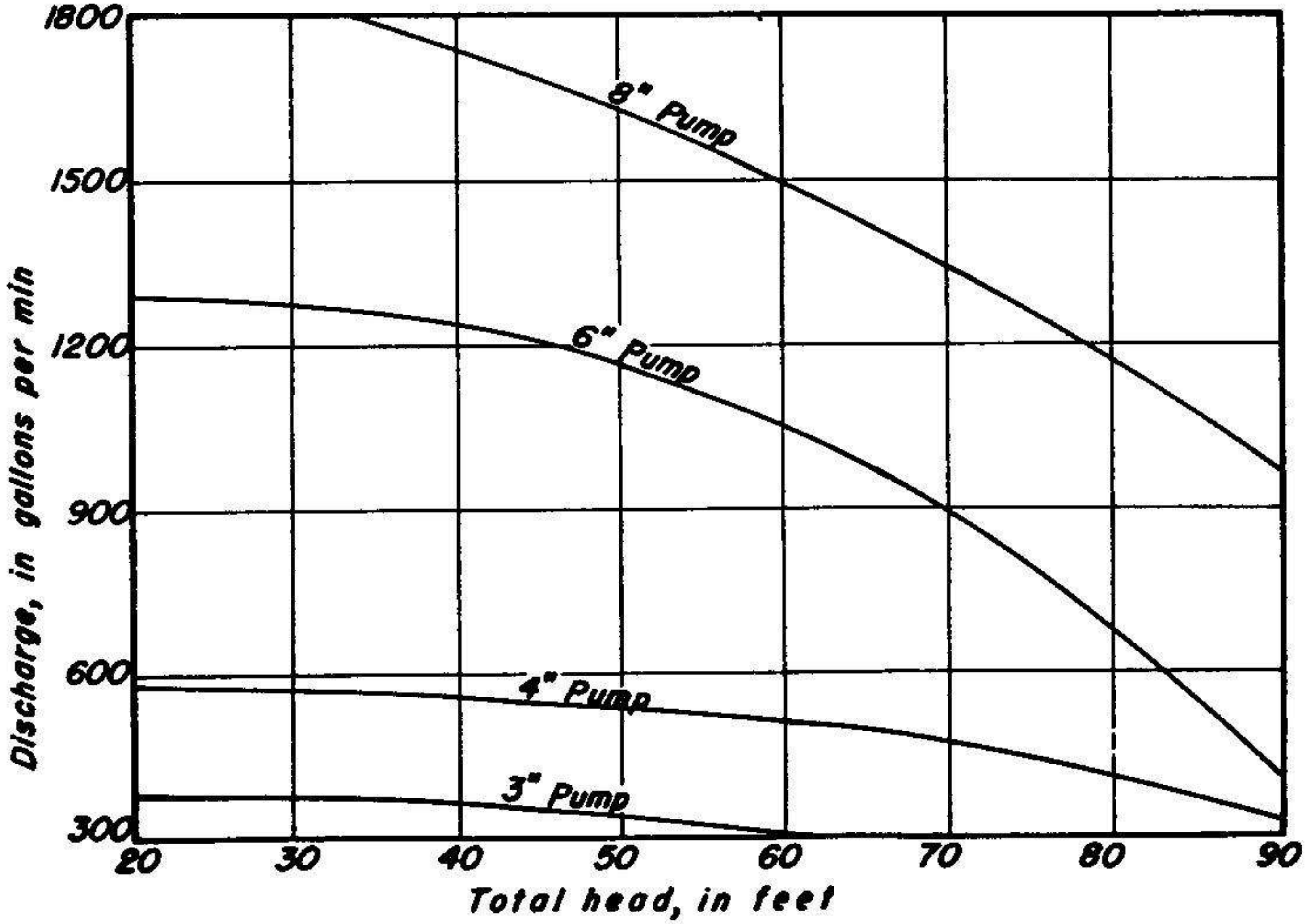
Carson (1961)

Head vs. Discharge for Pump



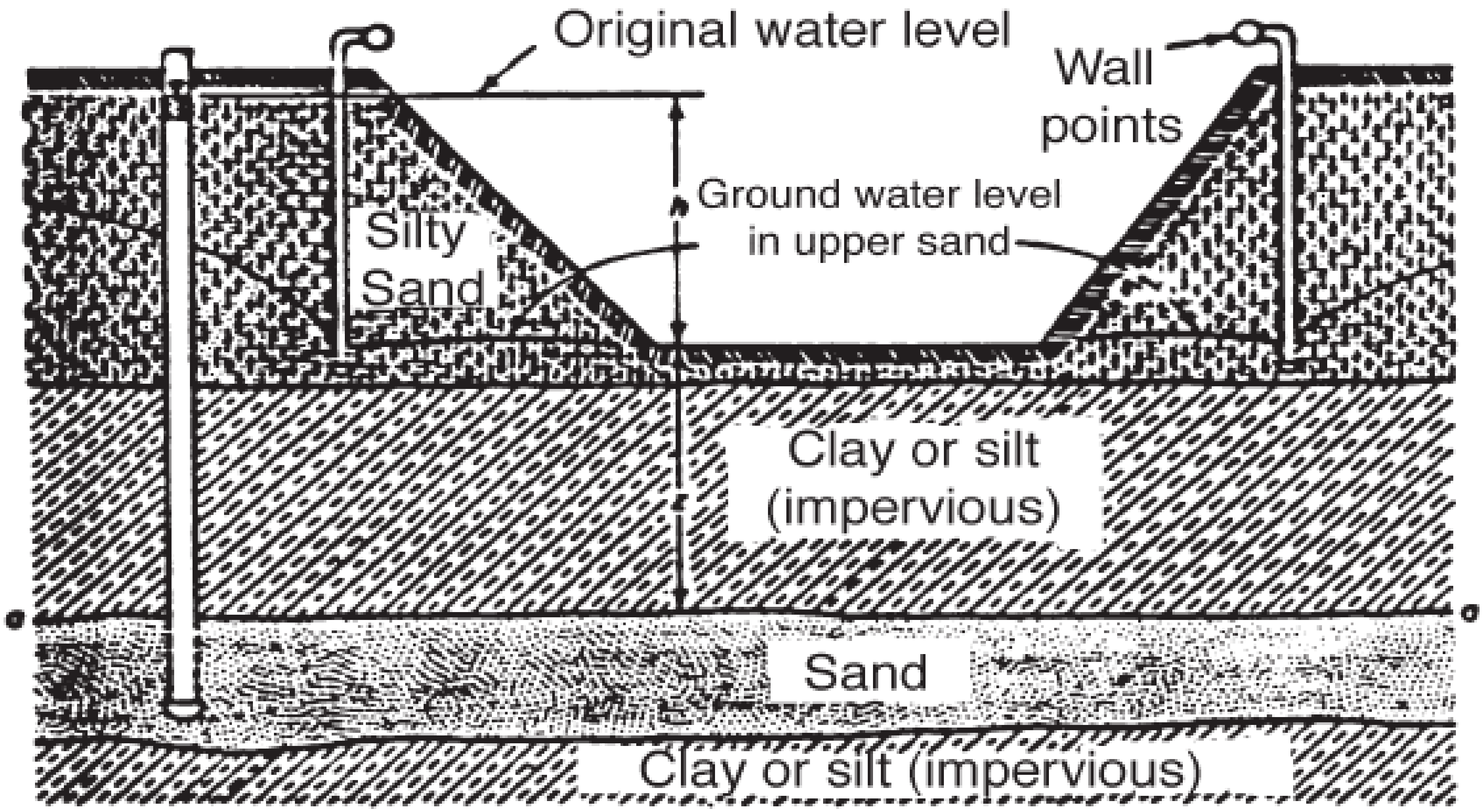
Carson (1961)

Head vs. Discharge for Pump



Carson (1961)

Bottom Stability of Excavation



$\gamma z > \gamma_w (h + z)$

Caltrans

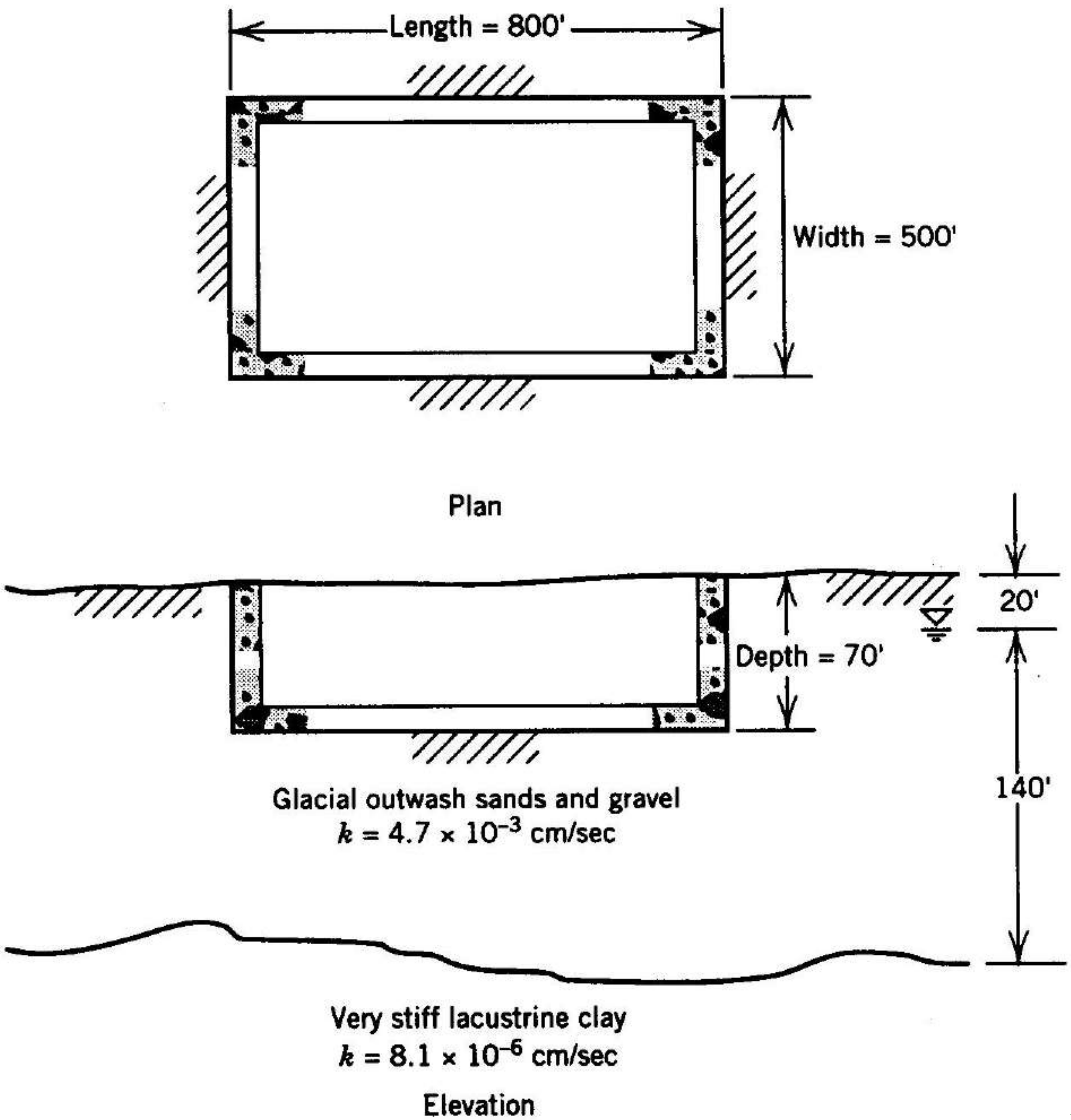
Settlement of Adjacent Structures

$$\delta = \frac{H}{1+e_0} C_c \log \frac{\sigma'_{vo} + \Delta\sigma}{\sigma'_{vo}}$$

$$\Delta\sigma = \Delta h \gamma_w$$

Δh = reduction of groundwater level

Examples



240m lengthx150m widthx21m depth

Plan View & Cross-Section

Xanthakos et al (1994)

Design Requirement

Lower the groundwater table to 1.5m below the bottom of the excavation

Equivalent Radius and Influence Range

Equivalent radius of excavation

$$r_0 = \sqrt{\frac{800\text{ft} \times 500\text{ft}}{\pi}} = 357\text{ft}$$

112.5m

Height of water level in well

$$h_0 = 160 - 70 - 5 = 85 \text{ ft}$$

25.5m

Influence range

$$R = C'(H - h_w)\sqrt{k} = 3000 \times (140 - 85) \times 0.3 \times \sqrt{4.7 \times 10^{-5}}$$

$$= 340\text{m} = 1130\text{ft}$$

339m

Rate of Flow in Wells

Using Darcy's law

$$Q = 1.571k \frac{(H - h_0)(H + h_0)(R + r_0)}{R - r_0}$$

$$= 1.57 \times 0.00925 \times \frac{(140 - 85)(140 + 85)(1130 + 357)}{1130 - 357}$$

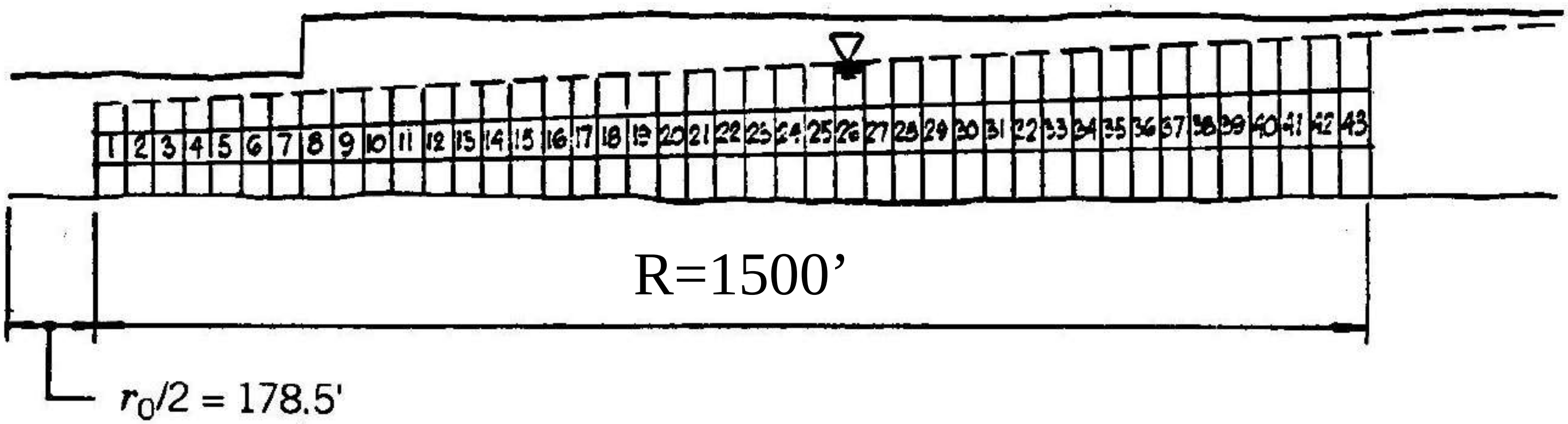
$$= 346 ft^3 / min = 2592 gal / min$$

Single well formula

$$Q = \frac{1.37k(H^2 - h_0^2)}{\log(R - r_0)} = \frac{1.37 \times 0.00925 \times (140^2 - 85^2)}{\log(1130 / 357)}$$

$$= 313 ft^3 / min = 2350 gal / min$$

Flow Rate into Wells using Flow Net



$$Q = 3.14k\left(H - h_0\right)\left(R + r_0\right)\frac{n_f}{n_d}$$

$$= 3.14 \times 0.00925 \times (140 - 85) \times (1130 + 357)\frac{3}{30}$$

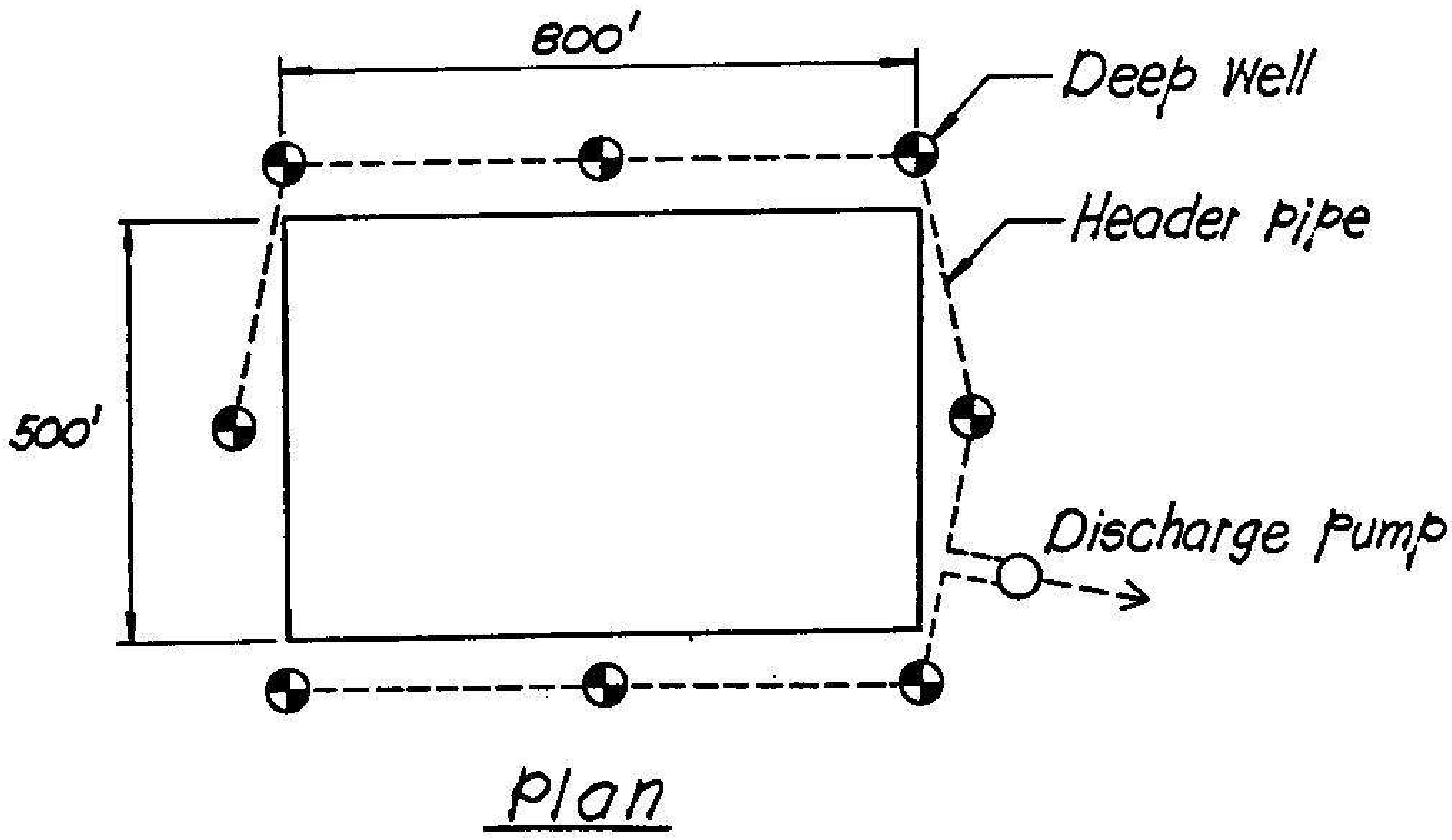
$$= 238\mathrm{ft}^3/\min = 1782\mathrm{gal}/\min$$

Pump Test

A pump test indicates that the field permeability
$k = 9.2 \times 10^{-4}$ cm/sec and the radius of influence
R = 2200ft. The new solutions based on the pump
Test results are

Method	Darcy's law	Well formula	Flow net
Q (gal/min)	370	290	360

Layout of Deep Wells



Xanthakos et al (1994)

Multiple Wells

$$Q = \frac{\pi k\left(H^2 - y^2\right)}{\ln R - \ln a} = \frac{3.14 \times 0.00181 \times \left(140^2 - 85^2\right)}{\ln 2200 - \ln 357}$$

$$= 38.7 ft^3 / min = 290 gal / min$$

290/8 = 36.3 gal/min per well

Deep well size:

4” dia. for 36.6 gal/min

Header pipe:

4” dia. for 5 x 36.6 gal/min = 181 gal/min

Discharge pump:

4” dia. Pump for 290 gal/min