Wells, Pumps, & Water Management

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1. Introduction:

Crops use water for cooling, nutrient transport to the leaves, and photosynthesis. Most of the water used by the crop evaporates from the surface of the leaves. Plants function like an evaporative cooler where large amount of water is used for cooling which is an integral part of the photosynthesis process. The growth of plant is tied to the ability of leaves to produce carbohydrate via photosynthesis. The carbohydrate is the basis for the accumulation of biomass and growth of the plant. The leaves capture light over the surface area of the leaves exposed to the sun. Upon exposure to the sun energy, the leaves open thousands of tiny pores (stomata) to let in carbon dioxide (CO_2) and solar energy to produce carbohydrate. The open stomata and solar energy also results in water evaporation at the same time. The water evaporated through the stomata is referred to as transpiration. The sum of water loss through transpiration and evaporation outside of stomata such as soil surface is referred to as evapotranspiration (ET). The ET is a function of climate condition, plant leaf area and the stomata behavioral characteristic of the plant. The water which evaporates through ET is supplied from the stored moisture within the root zone of the plant. Thus the success of the crop growth and yield production depends on the climate, the plant and ability of the producer to provide the soil reservoir with timely and sufficient quantity of water. While successful crop production requires nutrient, proper seed, weed, disease and pest management, water is the key factor in maximizing yield. *Water is the single most important production parameter in irrigated agriculture*. Irrigation water can be obtained from surface sources such as river or stream or it can be obtained by drilling well or a combination of both. This manual describes how a well can be drilled and managed for optimum economic return in an irrigated agriculture. Agriculture is a business and management of resources should be focused on not getting just the highest yield, but the highest economic output and part of the highest economic output is minimizing the cost of water.

2. Drilling a water well:

Well needs to be drilled in a groundwater formation which can produce sufficient good quality water. However, a proper groundwater may not necessarily provide sufficient good quality water if the well is not properly drilled or managed. Before a well driller can be contracted, a well design should be put together (unless the well driller can provide the design). The ultimate goal of a water well should be to produce the required water for irrigation with minimum cost.

2.1 Properly constructed water well

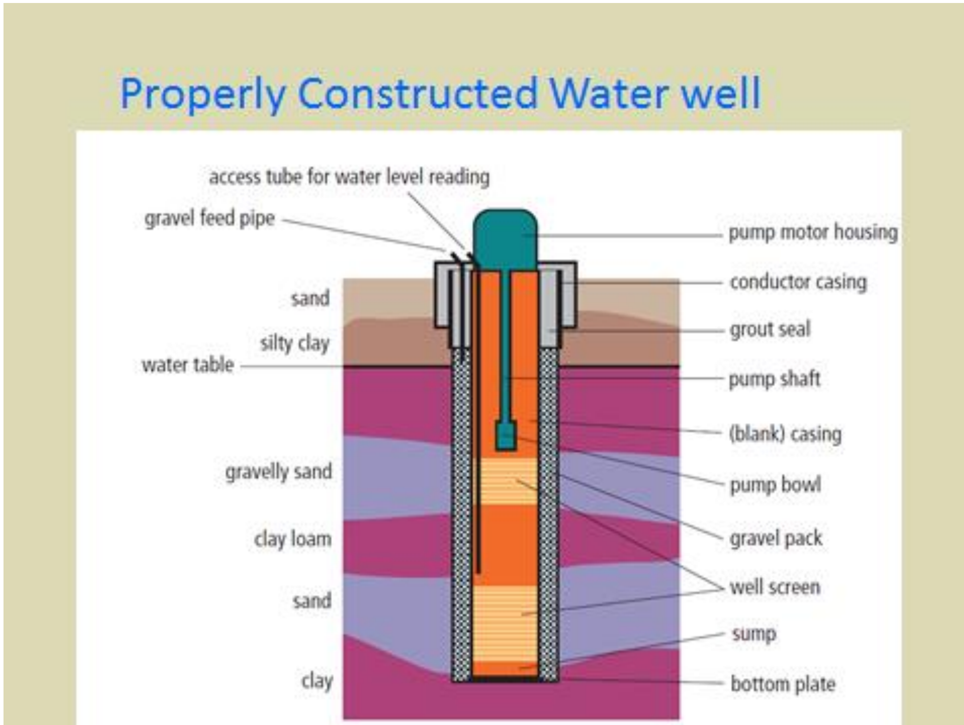


Figure 1. Components of a propeller well

Figure 1 shows the components of a properly constructed well. A well consists of the following components;

1. Casing
2. Screen
3. Gravel pack
4. Grout
5. Access tube
6. Bottom plate

2.2 The parameters

The parameters which need to be determined for design and construction of wells are;

1. How much water

2. What diameter
3. How deep
4. Cost

1. **How much water**. The amount of pumping rate (l/s or gpm) is the first parameter which needs to be determined. The pumping rate should be sufficient to meet the irrigation water requirement during the peak demand period. Crops water requirement changes with time and type of crop or crop mix. Figure 2 shows the rate of consumptive use or ET on daily basis for a mature pecan orchard in New Mexico. As seen in figure 2, the peak pecan ET which occurs during the month of June is 9.5 mm/day. However, for practical purposes, it is better to use the highest weekly water use which in this case is 8.5 mm/day A pump designed to irrigate this field should be able to meet the peak weekly demand. Using the continuity equation;

$$Q.t= A.d \qquad (1)$$

Where Q is pumping rate in m3/s, t is duration of irrigation in sec, A is the area in ha, and d is gross daily ET requirement. The peak ET in figure 2 is 8.5 mm/day. The crop in the area is irrigated with basin flood irrigation with efficiency of 65%, thus the gross average peak daily water demand is 8.5/0.65 = 13 mm/day. The minimum pumping rate for one ha in this case can therefore be calculated as;

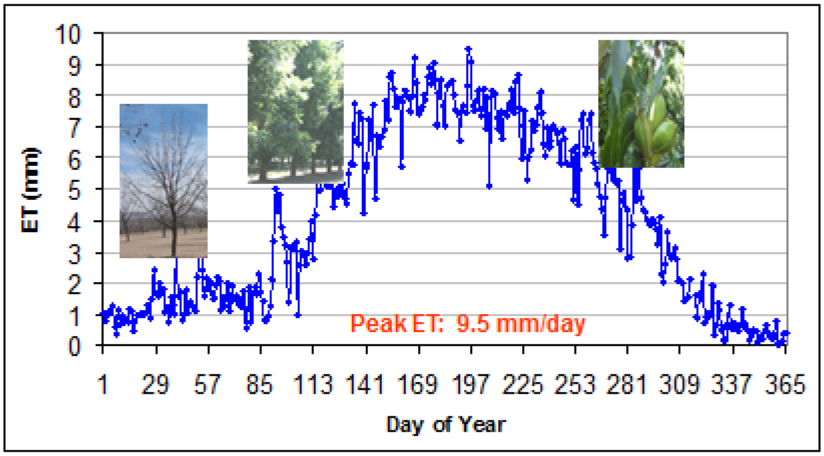


Figure 2. Daily crop ET for Pecan, NM, U.S.A

Q(2400)(3600)=10,000 x0.013

Which results in Q of 0.0015 m3/s/ha. This means that the pumping rate should be 1.5 l/s/ha. This translates into about 10 gpm/acre. The assumption here is that the field is going to be irrigated continuously (24 hour/day) during the peak demand period. If someone has a large field such as 100 acre, then the pumping rate required for this condition is;

100x10 = 1000 gpm

Therefore a pump producing 1000 gpm, can irrigate this field of 100 acres. This does not mean that the famer is going to irrigate the entire 100are farm every day. In practice, the farmer can divide the farm into 10 section (10 acre each) and irrigate each section in one day. If this farm is being irrigated by a solid set drip system, then the entire farm can be irrigated every day with the same 1000 gpm. However if the farmer decides to irrigate only during the day time at 8 hour/day irrigation, then the pumping capacity should be;

24/8(1000) = 3000 gpm

For a farmer who has a small field for example 5 acre, it wouldn't be practical to be irrigating every day. Therefore if the farmer decides to irrigate only once a week during the peak period, then the required pumping rate would be;

10gpmx(5 acre)x7 daysx(24/8)=350 gpm

But if the farmer wants to irrigate only once per week during an 8 hour period, then the required pumping rate is;

10 gpm (5 acre)x7 daysx(24/8) = 1050 gpm

The cost of the well and the pump in this case per acre will be relatively higher compared to the farmer who has 100 acres. The pumping capacity therefore is an economic compromise between the cost of labor and cost of well. Once the decision is made on the pumping capacity, the next step is to determine the size of the well. The size of the well comprises of the diameter and depth.   The cost of a typical well varies with diameter, depth, length of screen and type of material used for screen, casing and gravel. Figure 2 shows typical well cost using stainless steel continuous- slot screen and low carbon steel casing for year 2013 in New Mexico.

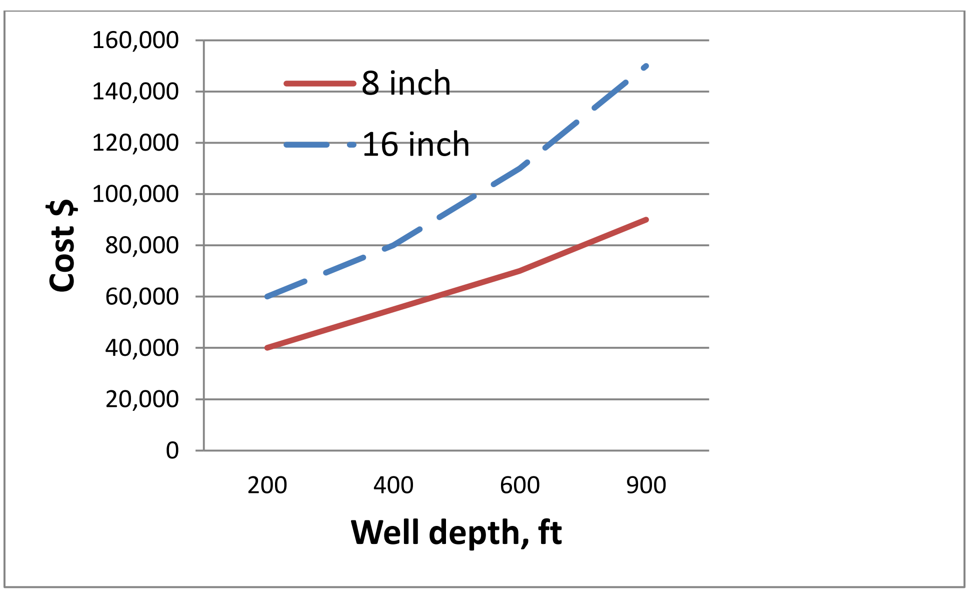


Figure 3. Typical well cost using stainless steel-continuous slot screen, 2013, Las Cruces,NM

2.3 well diameter

Well diameter should be large enough to accommodate the external diameter of the pump that is installed in the casing. The diameter of pump is directly related to the pumping rate. Higher diameter pumps can pump higher flow rate. While the actual external diameter of pumps for a given flow varies with the type of pump and the manufacturer, the following table 1 can serve as a rough guide to select the proper well diameter. Table 1 shows the required diameter of the well casing as a function of the desired pumping rate. The external diameter of the pump should be at least 2 inch lower than the diameter of the well casing.

1770 RPM			
Discharge, Q, gpm or L/s		Minimum Casing Diameter In or mm	
(gpm)	(L/s)	In	mm
<150	<9.5	8	200
150-600	9.5-38	8-10	200-250
600-1000	38-63	10-12	250-305
1000-2500	63-158	12-14	305-355
2500-3000	158-189	14-16	355-406
3000-5000	189-315	16-20	406-508
5000-7000	315-442	20-22	508-560
7000-9000	442-568	22-26	560-660
3450 RPM			
<120	<7.6	4-6	102-152
120-400	7.6-25	6-8	152-200
400-1000	25-63	8-10	200-250
1000-1400	63-88	10-14	250-355

Table 1. Well diameter as function of discharge rate and pump speed (samani 2009)

2.4 Well depth

As shown in figure 3, the cost of a well is directly proportional to the depth. The total depth of the well consists of length of casing plus length of screen plus 20 ft;

Total depth = Screen length + casing length +20 ft (2)

The 20 ft at the bottom of the well is called stool and is used as type of waste storage. The most important part of a well is screen.

2.4-a Screen length

The function of screen is to allow water into the well and to prevent sand and soil from entering the well. The length of screen is directly related to energy cost and pumping rate. Generally, the longer the screen the more water can enter into the well and the less it will cost. The way the length of screen affects the pumping rate and pumping cost is by affecting the transmissivity of the well. The transmissivity of the well can be defined as;

$T_{well} = Ks \times (Ls)$ (3)

Where T_{well} is the transmissivity of well, Ks is the saturated hydraulic conductivity of the formation next to the screen and Ls is the length of screen. The screen is installed in the productive zone of the water bearing formation which consists of sand, gravel or a mixture of sand and gravel (figure 1) and has good quality water. Well drillers can identify the appropriate location of screen by taking physical samples during the drilling and by conducting electric logs in the borehole. Figure 4 shows a typical geological well log prepared by a well driller. Geological well log should be accompanied by a geophysical log which shows not only the location of sand and gravel formation, but also the location of good quality water. Geophysical logs are expensive (typically about $5000-$6000), but are very critical in identifying the proper location of screen for good quality and sand free pumping operation. The most common geophysical logs are electric resistivity logs which are in units of Ohms Ohms-meter and Gamma ray logs which are indicator of presence or absence of clay. A borehole and subsequently the well has to be drilled deep enough to identify the location of screen. Figure 5 shows the geophysical logs for a borehole which was drilled down to about 1000 ft. In figure 5, the borehole shows very low resistivity starting from 70 ft to about 180 ft indicating poor quality water. Low resistivity is indicator of poor quality

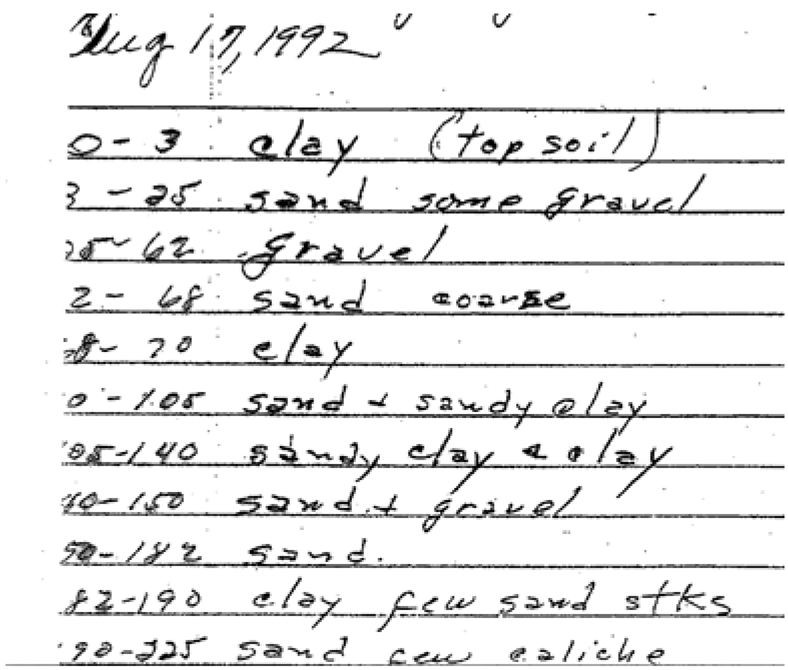


Figure 4. A typical geological well log

Water, clay or a combination of both. If there is clay in the area, then it can be identified using the Gamma ray information combined by the geological logs. Figure 6 shows the geophysical logs for the same borehole from 660 ft to 820 ft. The low resistivity and high gammay ray at 670-680 interval indicate the presence of clay layer which was also confirmed from geological logs. The high resistivity and low gamma ray values below 680 indicate good quality water and sand/gravel area which is ideal for screening. In this case, it was recommended to screen the well from 680-1000 ft (total of 320 ft) with wire wound continuous slot screen . The reason for screening below 680 ft was not only due to good quality and productive area, but also the presence of the clay layer at 670-680 ft which separated the formation from the lower quality water above. Therefore, the screen should be installed in areas of sand and gravel formation having high permeability and also good quality water which is separated from the rest of the formation by a clay layer. The annular space in the clay layer should be grouted to prevent short circuiting of poor quality water into the screen.

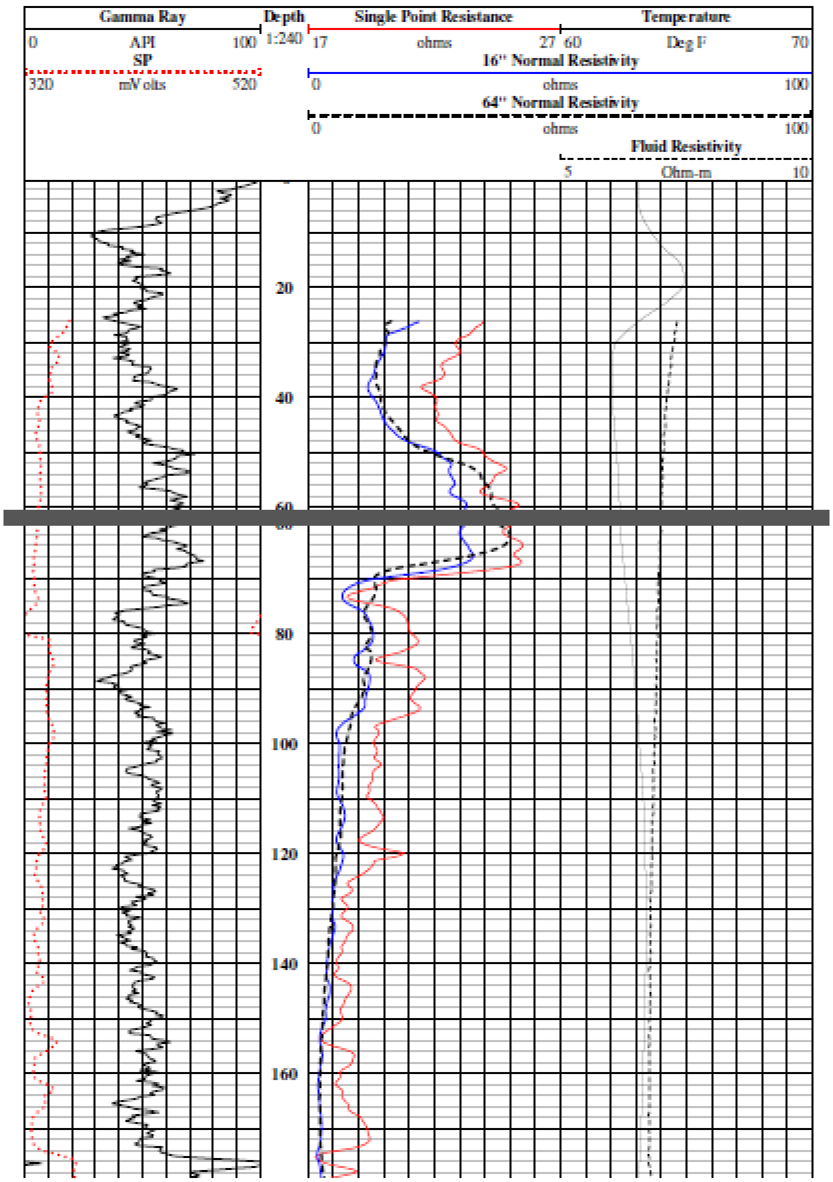


Figure 5. Resistivity and Gamma Ray logs for the first 180 ft.

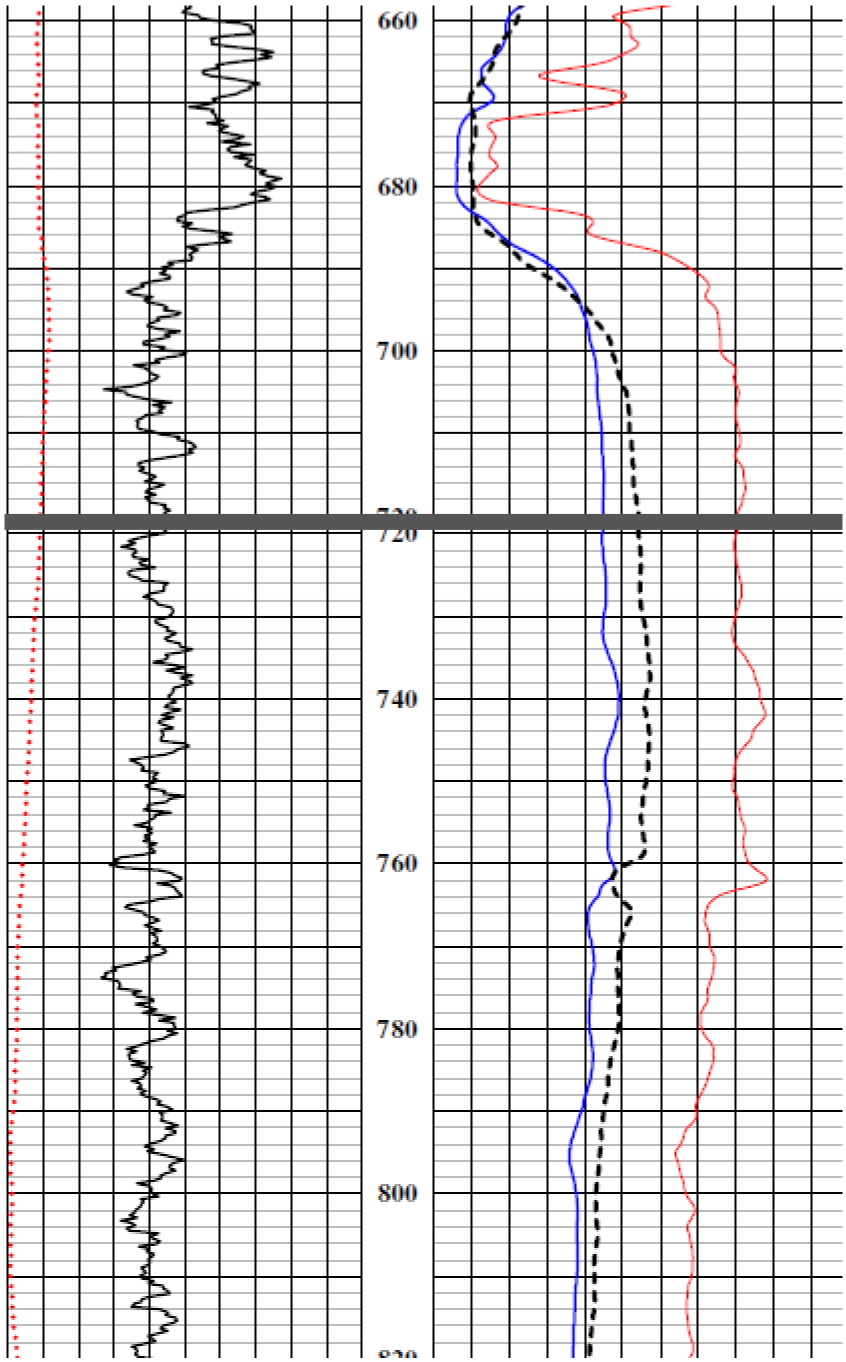


Figure 6. Resistivity and gamma ray logs below 660 ft.

Once the location of screen is identified, the type of screen and the screen opening should be identified. There are various types of screen with various open areas. Figure 7 shows the various types of screen typically available. The best type of screen is the wire wound continuous slot screen which have the largest opening area.

Figure 7. Various types of screen with opening area in square inch per foot of the screen for 0.125 inch slot size.

The opening area of the screen is critical in preventing sand pumping. Sand pumping is caused by high velocity of entrance into the well. The velocity of entrance of water through the screen should not exceed 0.1 ft/sec. The following equation demonstrates how to calculate minimum length of screen to avoid sand pumping.

$$Ls(in^2 / ft)(0.31) = Q \qquad (4)$$

Where Ls is the screen length, and Q is the pumping rate. In the above example, 320 ft of 16 inch diameter wire wound screen with screen opening of 96 inch/ft^2 was installed. The desired flow from this well was 3000 gpm. Using equation 4, the maximum sand free pumping rate is;

Q = 320x0.31x96=9523 gpm (5)

Which is higher than desired pumping rate. The screen length in the above example was 320ft. The screen length is a critical factor in not only pumping rate but also the energy cost. A simple formula to determine the potential drawdown in an unconfined aquifer is shown below;

$$Q / s = (Ls.Ks)(7.48) / 1500 \qquad (6)$$

Where Q/s is pumping rate in gpm/ft of drawdown, a term which is often referred to as specific capacity. In the above example, the hydraulic conductivity of the water bearing formation was about 20 ft/s. Using this values and 320 ft of screen length results in;

$$Q/s = (320 \times 20 \times 7.48) / 1500 = 31.9 \text{ gpm/ft.} \qquad (7)$$

Which means in order to pump 3000 gpm, from this well, a drawdown of 94 ft will occur. The pump should be installed at least 50 ft below the dynamic water level in the well and at least 20 ft above the first screen. In this case, the static water level in the well was 30 ft, adding another 50 ft plus the drawdown will result in pump location of;

Pump location = 30 + 50 +94 =174 ft

Therefore a minimum column length of 174 is required. The total depth of the well as indicated before is equation 2 is equal to length of casing plus length of screen plus 20 ft of stool in the bottom. In this case, the screen starts at 680 ft. Therefore the total depth of the well in this case is;

Total well depth = 680 + 320 + 20 =1020 ft

2.4-b Gravel pack and screen opening

Gravel pack and screen opening are designed by taking samples from the potential screen interval during the drilling process. The samples are washed and analyzed using standard sieve analysis technique. Figure 8 shows various samples taken from the screen interval. When there are variability in samples, the finest sample should be used for designing the screen. The finest sample has a D70 grain size of 6.4 thousands of an inch (6.4/1000 inch) in this case (fig. 8). To design the gravel pack, D70 is multiplied by a coefficient between 4-6, an average of five. Therefore the D70 of the gravel pack is calculated as;

D70 (gravel) =(6.4 /1000)x 5 = 32 thousands of an inch

The gravel pack is then designed with the following characteristics;

a. Gravel pack should have D70 of 4-6 times D70 of sample
b. Should be parallel to the general slope of the sample
c. Should have uniformity coefficient of less than 2-2.5

The uniformity coefficient is defined as the ratio of D40/D90

The proposed gravel pack and its range are shown in figure 8.

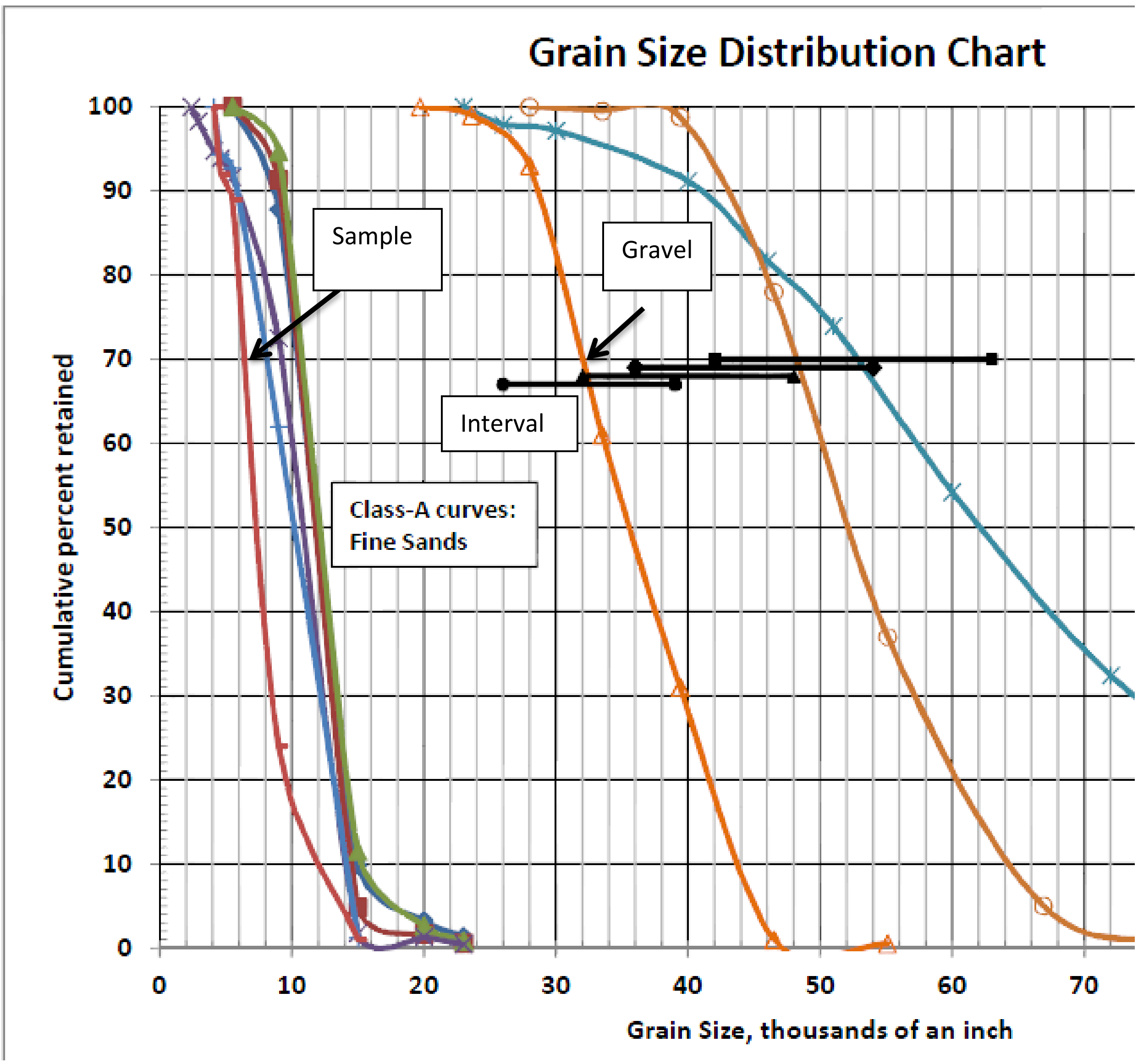


Figure 8. Sample and gravel pack

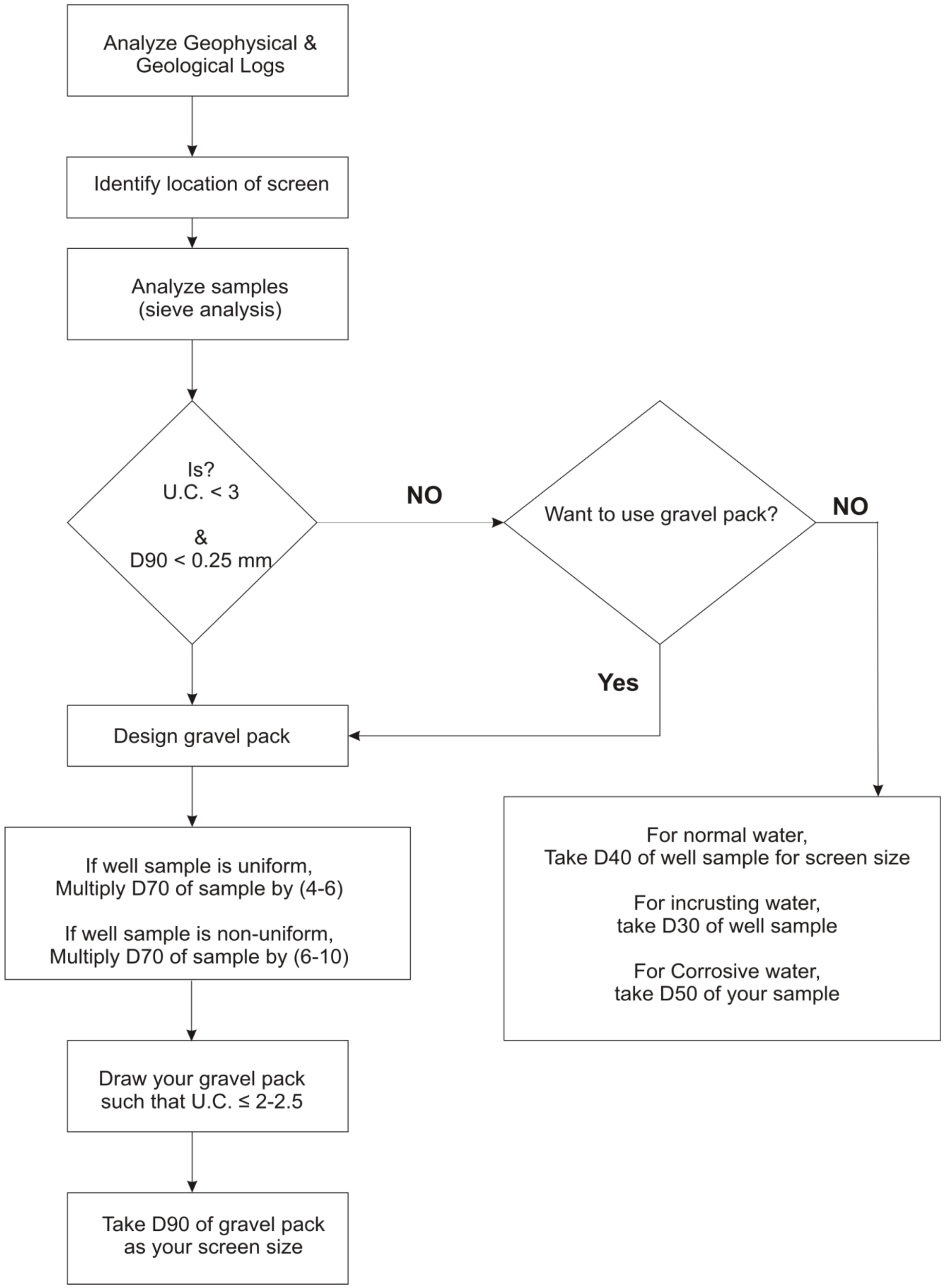


Figure 9. Flow chart for the design of gravel pack and screen

The screen is designed such that the screen opening is less than D90 of the gravel pack. In this example, the D90 of the proposed gravel pack is 28/1000 of inch. The commercially available screen sizes are 20/1000 or 30/1000 of inch. A conservative design in this case would be 20/1000 of inch. Even though in practice it would also be possible to use 30/1000 of inch due to the significant length of the screen in this case which results in a velocity of entrance of 0.31 ft/sec based on equation 4, which is considerably lower than the proposed 0.1 ft/sec.

In cases where the formation consist of larger size material or fractured formation not requiring a screen, the natural formation can be developed and used as filter pack. The flowchart in figure 9, can be used as guideline to decide on the need for gravel pack. If a well is drilled using a percussion technique with a telescopic screen, a gravel pack can be avoided if the natural material is suitable according to flowchart in figure 9. If a smaller screen is used, and there is space left between the screen and the natural formation, a gravel pack should still be used as a filler, even though it may not be required according to figure 9.

2.5 well Development

After installing the screen, gravel and casing, a well needs to be developed immediately to remove the drilling mud and the fine material from the formation. Failure to develop a well will result in sand pumping, low flow rate, high drawdown and consequently high energy cost. Some drillers may believe that the pump will eventually develop the well, but that is not recommended. An undeveloped well will result in damaging the pump, reducing the life expectancy of the well and will never fully develop once the drilling mud is consolidated. There are several ways to develop a well. These include

a. Surging
b. Air lifting
c. Jetting
d. Rawhiding

2.5-a Surging.

Surging is a process of alternately forcing water in and out of the formation. A tool similar to a piston is lowered into the well and then moved up and down. This creates a back and forth surging action through the screen that effectively moves the mud and fines into the well where they can be removed by air pumping or bailing (Fig. 10).

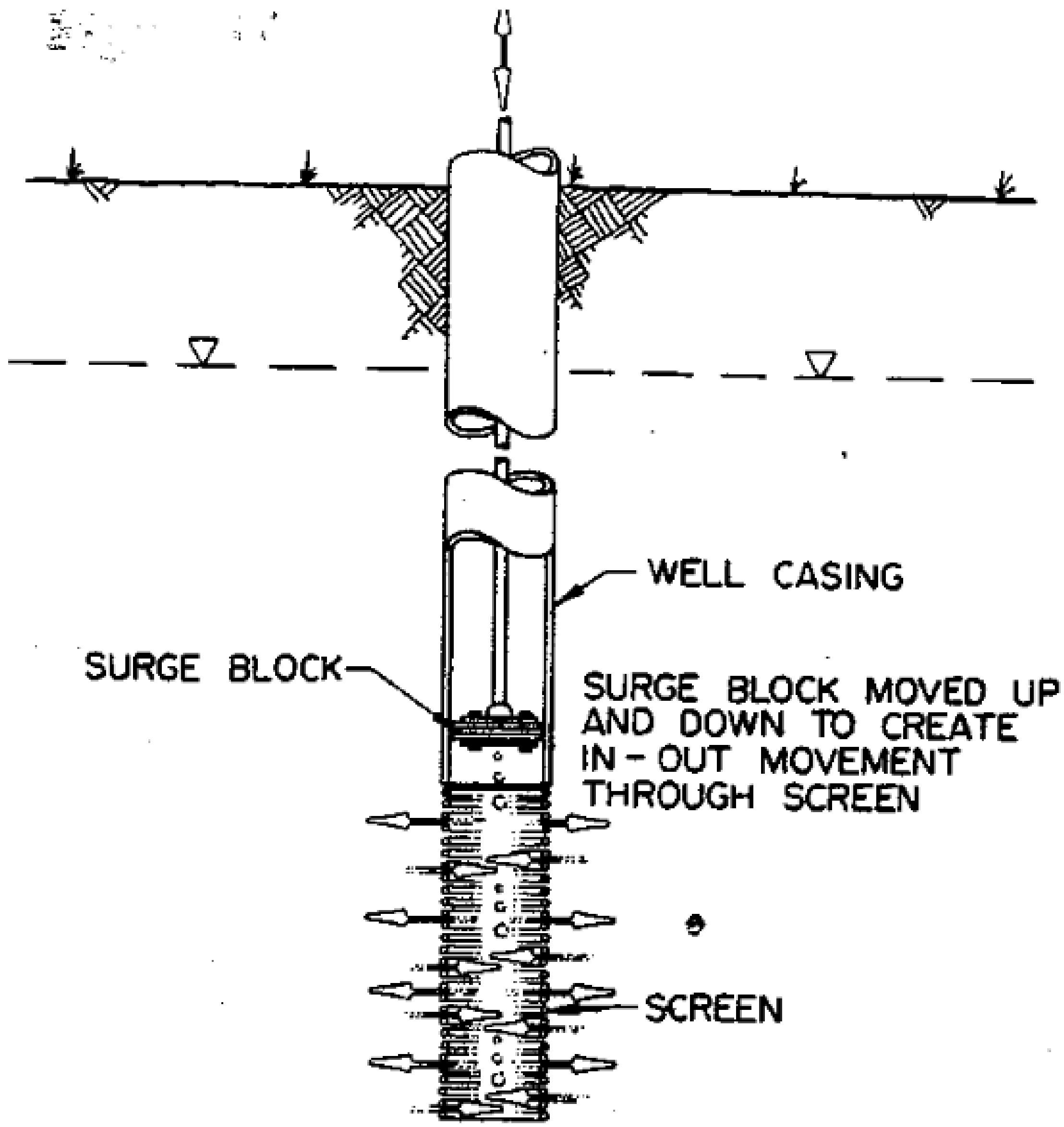


Figure 10. Surging is a process of developing wells after drilling

The piston can be moved up and down to concentrate the surging impact on various depths along the screen.

2.5.b air lifting

Air lifting or air pumping is a process where a large volume of compressed air is pumped into well through an airline. As the air rises in bubbles, it reduces the density of water and creates a surging effect which carries water and fines out of the well. To be most effective, air lift should be alternated with short periods of no pumping. This helps to back flush , forcing water out of the formation and into the well and breaks up the bridging of sand and gravel around the screen openings (fig. 11). Air development is only effective when there is sufficient depth of water in the well to get the surging (up and down) action. Air lifting does not work where the lift to the surface is great.

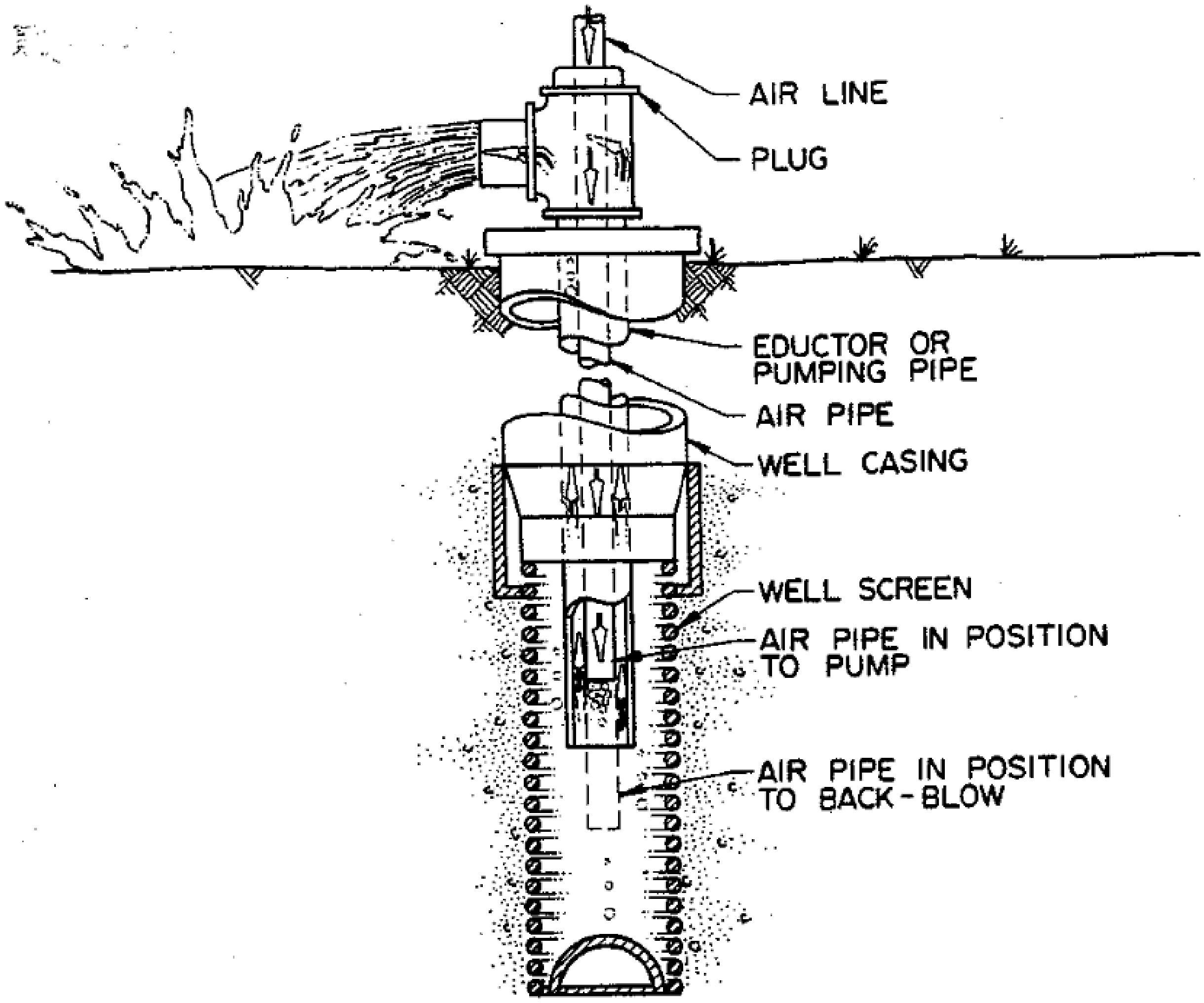


Fig. 11 Air pumping is a process of well development in low static water level condition

2.5.c Jetting

Jetting is the most powerful and effective method of well development. In this process high pressure water or air is pumped into the well. The water jetting can also be combined by air lifting. The air jetting serves as jetting and air lifting at the same time. Water or air is jetted at high velocity through the screen openings and gravel pack into the formation to loosen and break down the fine materials (Fig 12). The special tool that is used for jetting is rotated slowly and is moved up and down inside the screen. The simultaneous air lift pumping removes and loosens the sand and mud as it enters the screen. Jetting is most effective only when continuous slot screen and is not very effective with other types of screen such as slotted pipe, bridged or louvered screen.

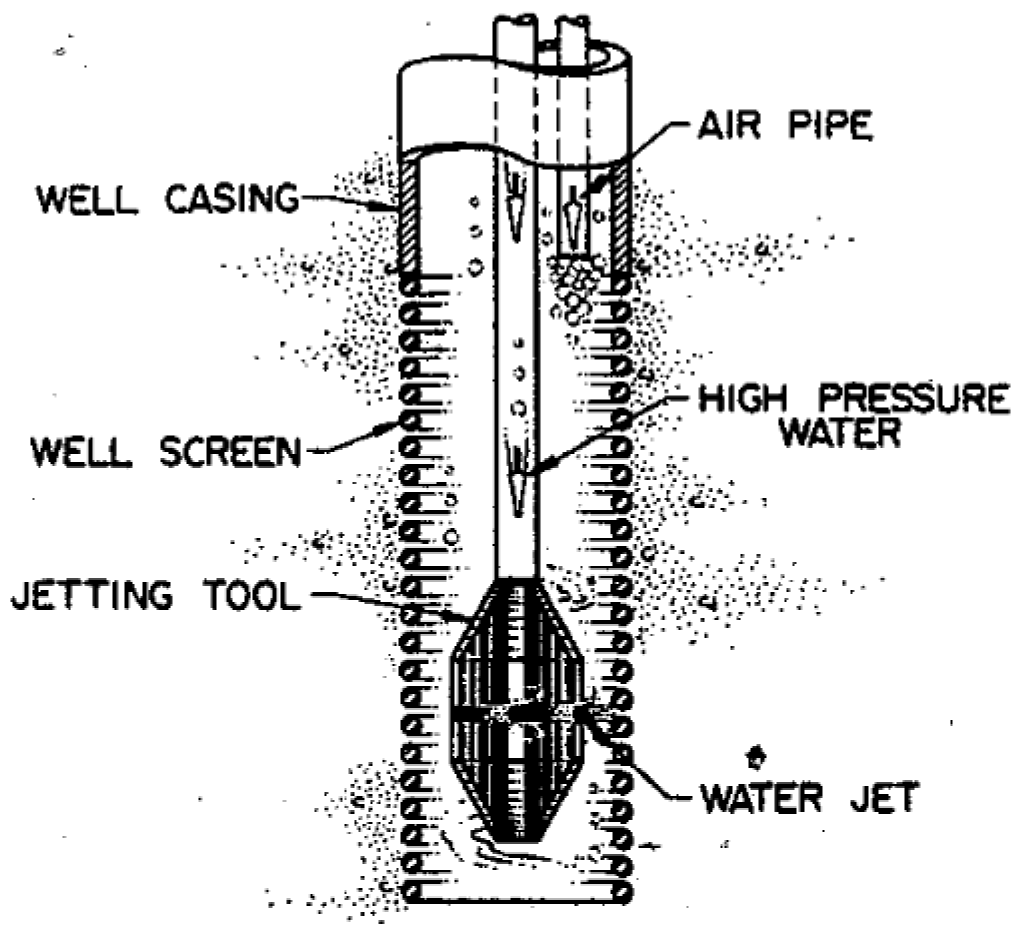
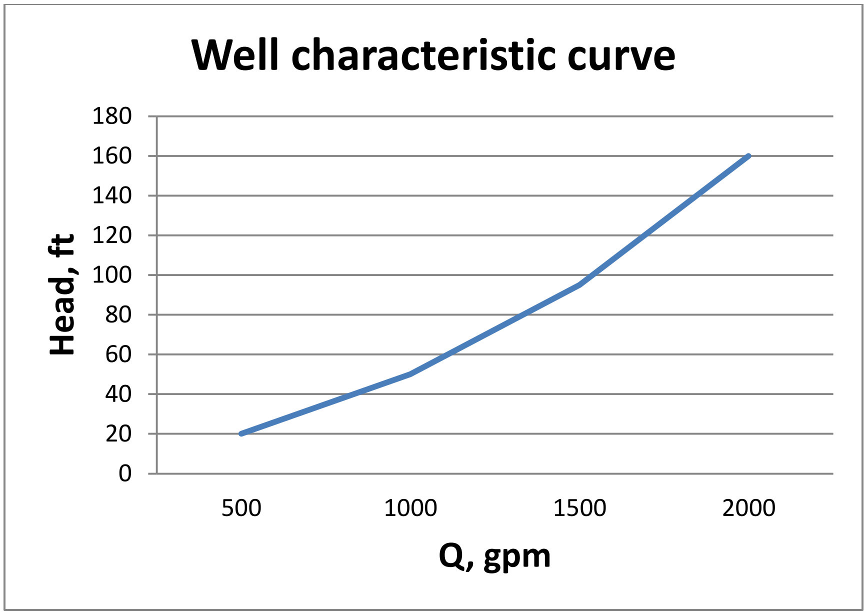


Fig 12. Jetting with air or water is the most effective method of development

2.6 Pump design and selection

2.6. a. Well testing

Prior to selecting a pump, a well should be tested after the development to determine the well characteristic curve. The well characteristics curve is the relationship between pumping rate and drawdown (fig. 13).



Using the well characteristic curve and desired pumping rate, the drawdown and the total dynamic head required by the pump can be calculated as;

2.6.b Pump selection

Total head = drawdown + SWL + friction loss + exit pressure (8)

The pump should be selected based on the following criteria;

a. The pump should provide the desired pumping rate and the required head (eq. 8)
b. Have high efficiency at the operating point
c. Operate at the right hand side of peak efficiency point

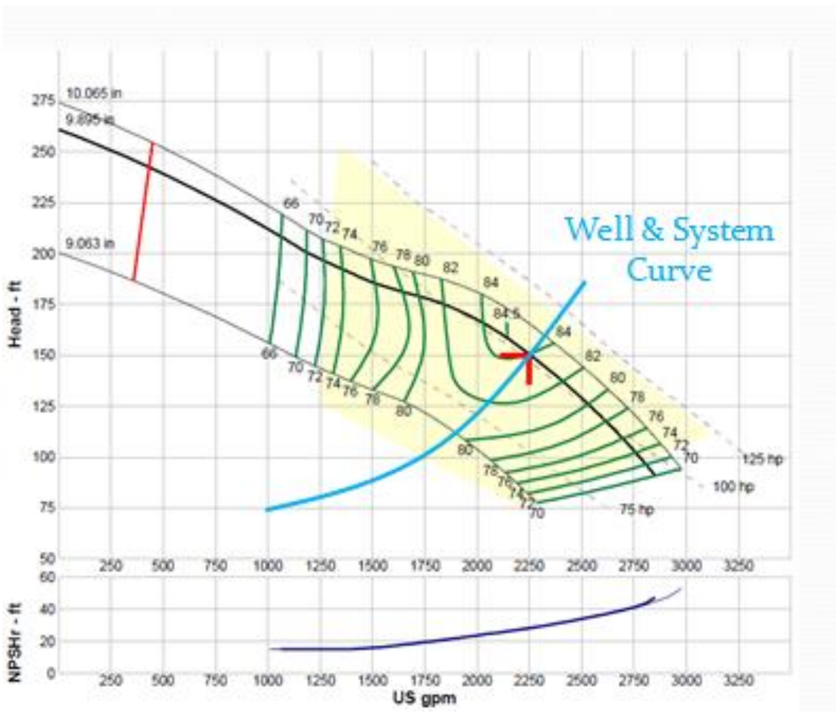
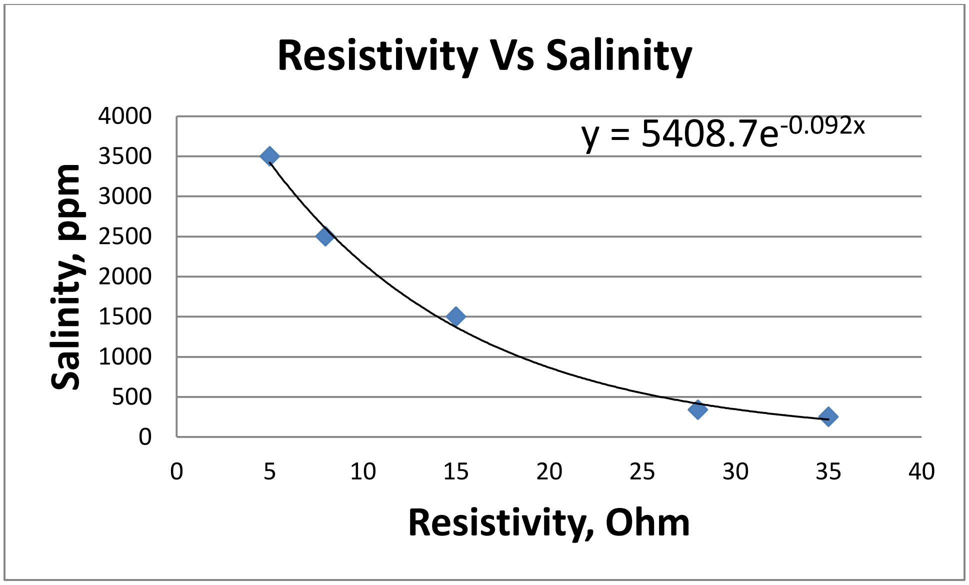


Fig. 14 pump selection

It is highly recommended that the well be tested prior to selecting the pump. If that is not possible, an approximation of the well specific capacity can be made using equation 7, if there is sufficient information available on the hydraulic conductivity of the aquifer adjacent to the screen. This type of information can be obtained from existing nearby well.


Resistivity Vs Salinity
y = 5408.7e-0.092x
Salinity, ppm
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
Resistivity, Ohm