Problems in Designing Boreholes Safe Yield

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Abstract

In most parts of Ethiopia for the purpose of designing of safe yield of boreholes, traditionally design yield is calculated by using the safe yield formula, whose actual source is not clearly understood. This safe yield formula is a linear equation, which doesn't actually represent the behavior of flow after certain pumping rate and results in erroneous conclusion. Therefore, in this paper the limitations of the equation and methods of utilizing it would be presented.

Introduction

For design purpose boreholes sustainable discharge without creating excessive drawdown has to be determined. To find the design yield of a borehole many hydrogeologists in Ethiopia traditionally use the safe yield equation. This formula is a linear equation whose application is limited only within a range where drawdown is directly proportional with discharge. This situation only occurs within certain limits as long as flow towards the well is in a laminar condition. After certain rate of pumping the flow in the well becomes turbulent and draw down increases to a power of some positive number and no longer becomes proportional to pumping rate. Designing a well yield by extrapolating from safe yield formula without understanding the behavior of the well has high risk resulting in over design, which would result in an excessive drawdown.

Safe (or design) yield formula

Safe yield is calculated by taking the specific capacity of the well at the stabilized drawdown (or from long duration test pumping), available head and safety factor.

$S_y = S_c * A_{dd} * SF$.

Where S_y is the safe yield (L^3/T), S_c specific capacity ($L^3/T/M$ or L^2/T), A_{dd} available design head (drawdown) and SF safety factor.

The design head (or available drawdown) in most cases taken as the difference between the static water level and the top of the first screen or the difference between the static water level and any head above the screen taking into account the pump positions and other parameters depending up on the individual well characteristics.

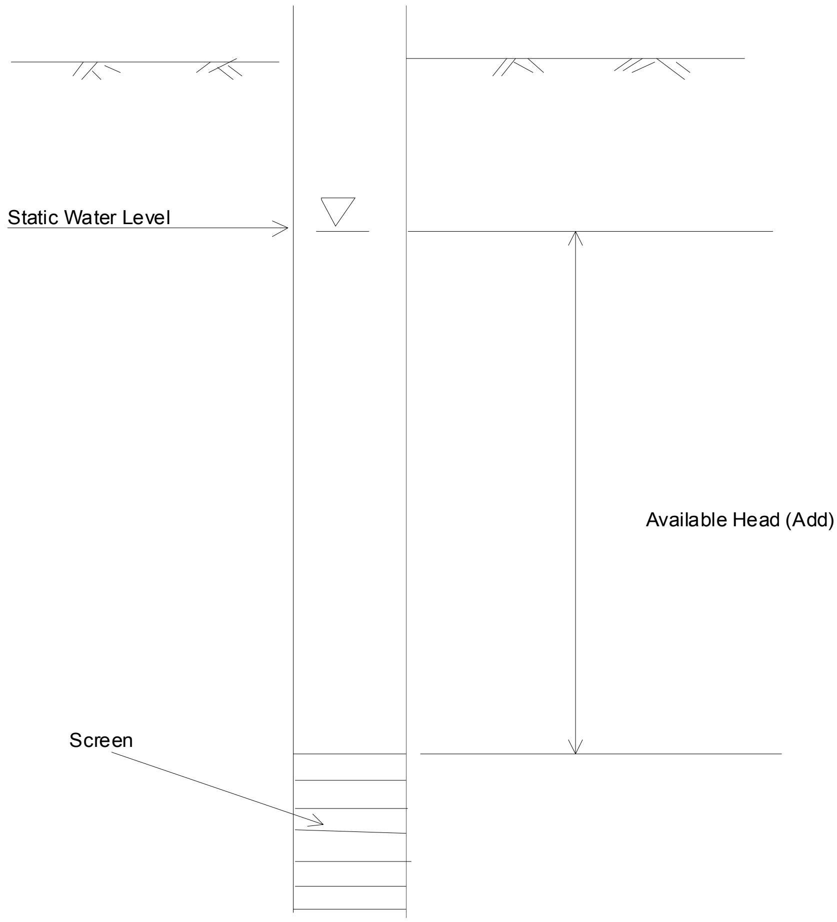

Figure 1. Total available head in a well up to the top of the first screen

Safety factor is introduced which can take into account uncertainties during pumping depending on weather changes, deterioration in the efficiency of the well with time resulting from clogging of screens due to incrustation or siltation.
There is no as such standard safety factor introduced. The safety factor depends on the judgment of the designer depending on the hydrogeological set up, climatic conditions and the water quality in the well. But generally it can range between 60% and 80 %. For example in waters where incrustation is anticipated the safety factor should be low. In areas where there is good water quality, with sand and gravel aquifer and appropriate screen design and low seasonal water table fluctuation, high safety factor can be considered.

Specific capacity is calculated by dividing the pumping rate with drawdown created due to pumping.

Specific capacity is variable for different pumping rates. Theoretically the pumping rate and the drawdown are linearly proportional for laminar flow condition. However, above certain pumping rate turbulent flow creates an excessive drawdown and linear proportionality is violated and drawdown increases exponentially.

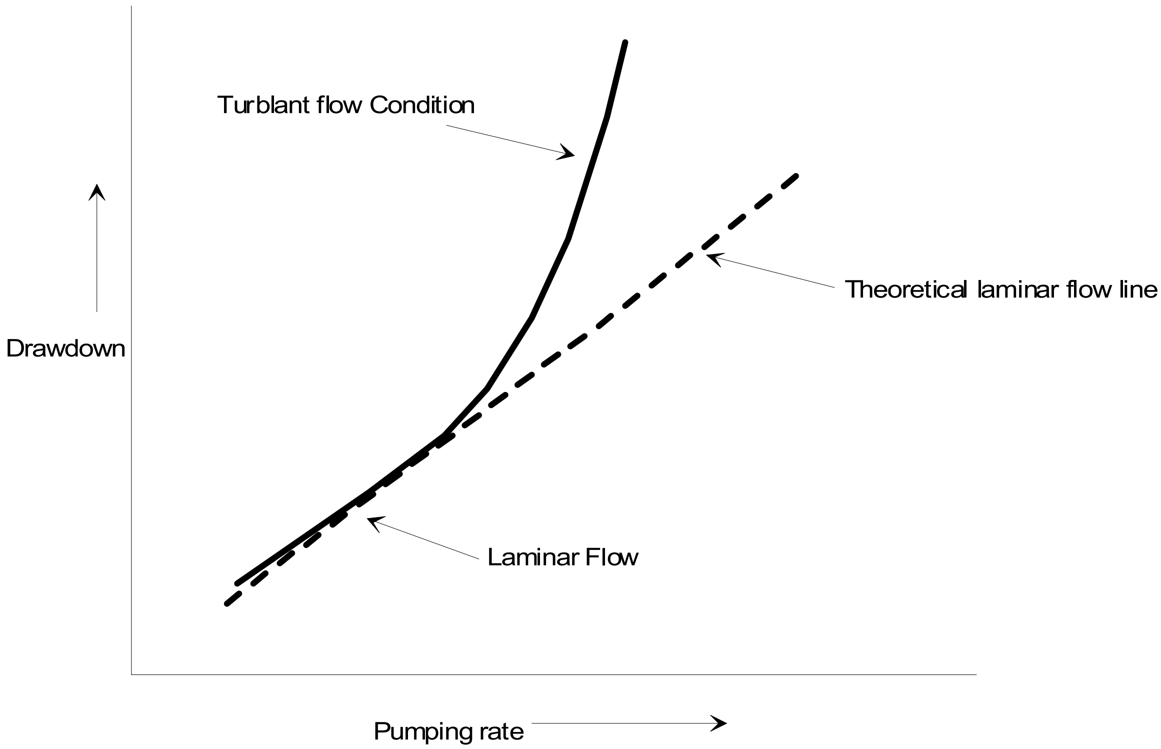

Figure 2. Theoretical curve showing laminar and turbulent flow condition

Specific capacity in fractured rocks varies significantly with an increase in the pumping rate. The extent of this decrease depends on the geologic origin of the aquifer on subsequent chemical and physical changes that may produce jointing, cementation solution cavities and faulting. Loss of specific capacity is best examined by conducting a step drawdown test. The following figures (Fig 3 through 8) show some of the variation in specific capacity obtained from step tests conducted in fractured rocks from some parts of Ethiopia.

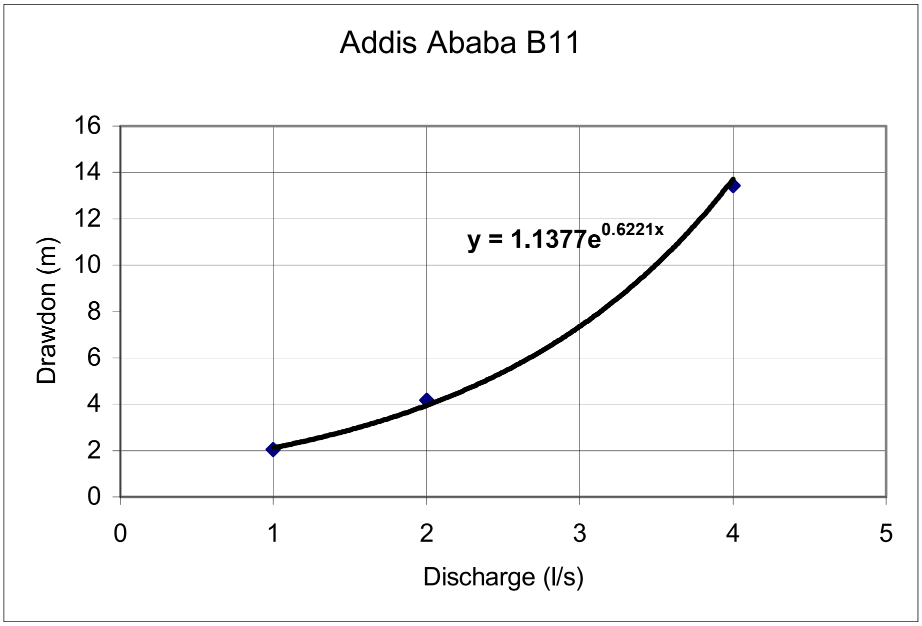

Figure 3. Step test result of a well drilled in fractured trachyte Western Addis Ababa

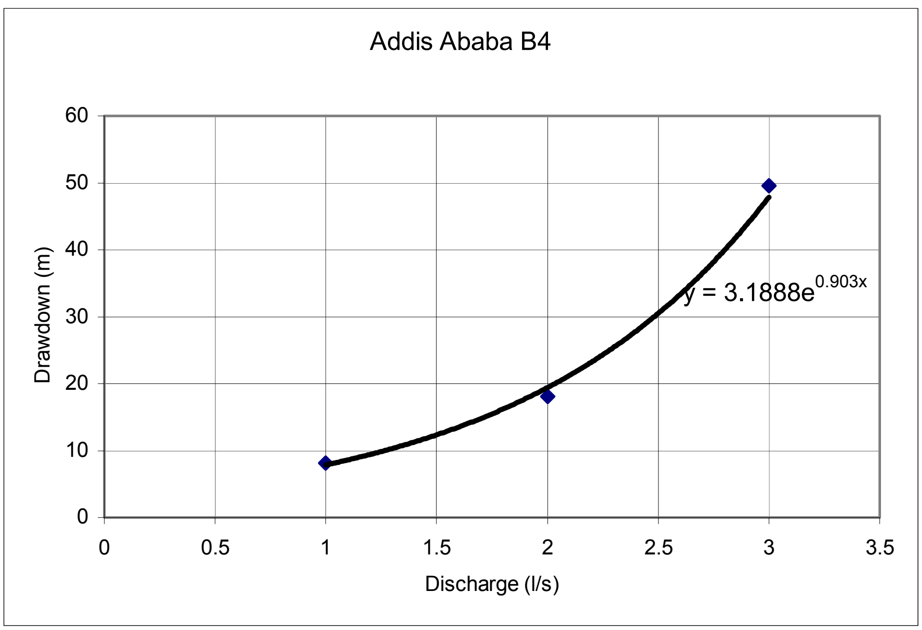

Figure 4. Step test result of a well drilled in fractured amygdaloidal basalt (northeast of Addis Ababa)

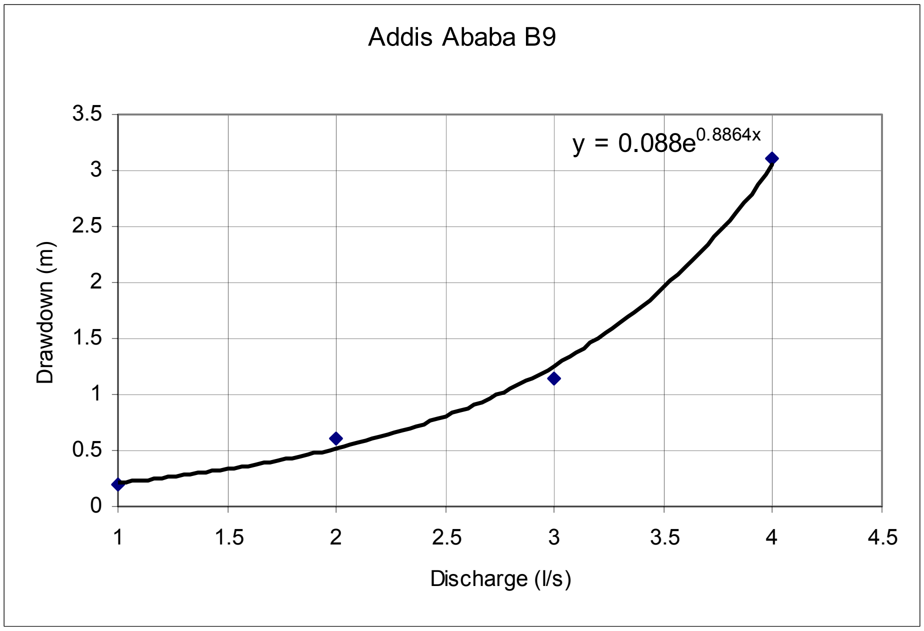

Figure 5. Step test result of a well drilled in fractured vesicular basalt with scoria (South east of Addis Ababa)

Figure 6. Step test result of a well drilled in a fractured volcanic rock (Woldya Northern Ethiopia)

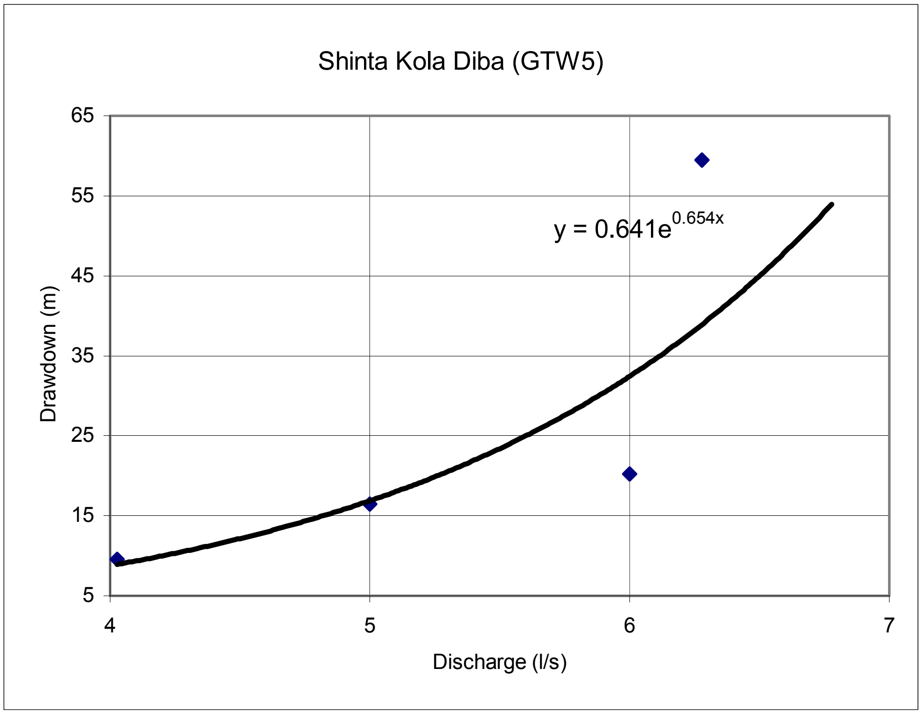

Figure 7. Step test result of a well drilled in fractured basalt,(Gonder northern Ethiopia)

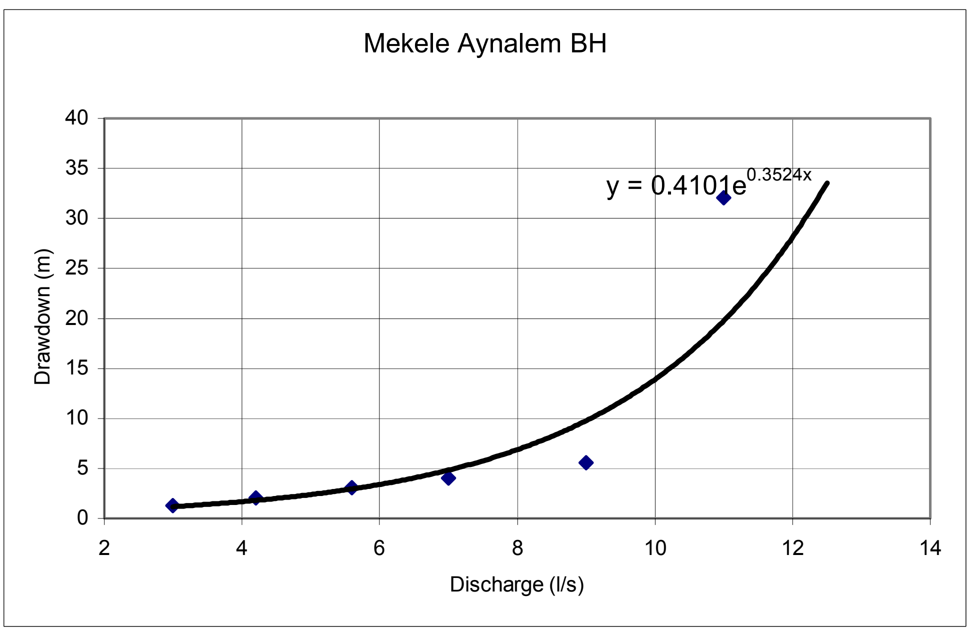

Figure 8. Step test result of a well drilled in a fractured dolerite and limestone (Mekle Northern Ethiopia)

Application of Safe Yield Formula

Safe yield or design yield equitation is a linear equation, which assumes that drawdown is proportional to discharge. As shown in the figures above drawdown especially in fractured rocks does not behave linearly. After certain discharge rate the drawdown changes exponentially with increased discharge rate. Therefore, extrapolating as a design discharge beyond the actual observed discharge and drawdown would result in an erroneous design. This would result in higher drawdown than expected from the design. This would create pumping interruption if the drawdown reaches the pump position or in cases where the pump is set below the first screen, in a multi-screen wells, which is common situation in fractured rocks, the drawdown would expose some of screens resulting in much higher drawdown.

The following example shows the possible problems that can be faced by using the safe design yield formula. As shown in figure 9 and table 1 the well is drilled in a fractured volcanic rock at Nefas Mewcha (northern Ethiopia), test pumped using both step and constant discharge test methods. The step test result shows that the drawdown changes exponentially with increased discharge. The behavior of the well with increased discharge is extrapolated from an exponential equation fitted to the step test result. Taking the value of the specific capacity (l/s/m) from the constant discharge test (0.297 l/s/m) the drawdown for different discharge rates is computed using the safe yield formula. This gives a line, which shows a proportion increase of drawdown with discharge. Taking into account the available head in the well, which is 77.5 m, and 60% safety factor, the drawdown in the well should be 46.5 m with a discharge rate of 13.6 l/s. However, in actual condition the well will have 60 m of drawdown, which is beyond the expected drawdown in the well.

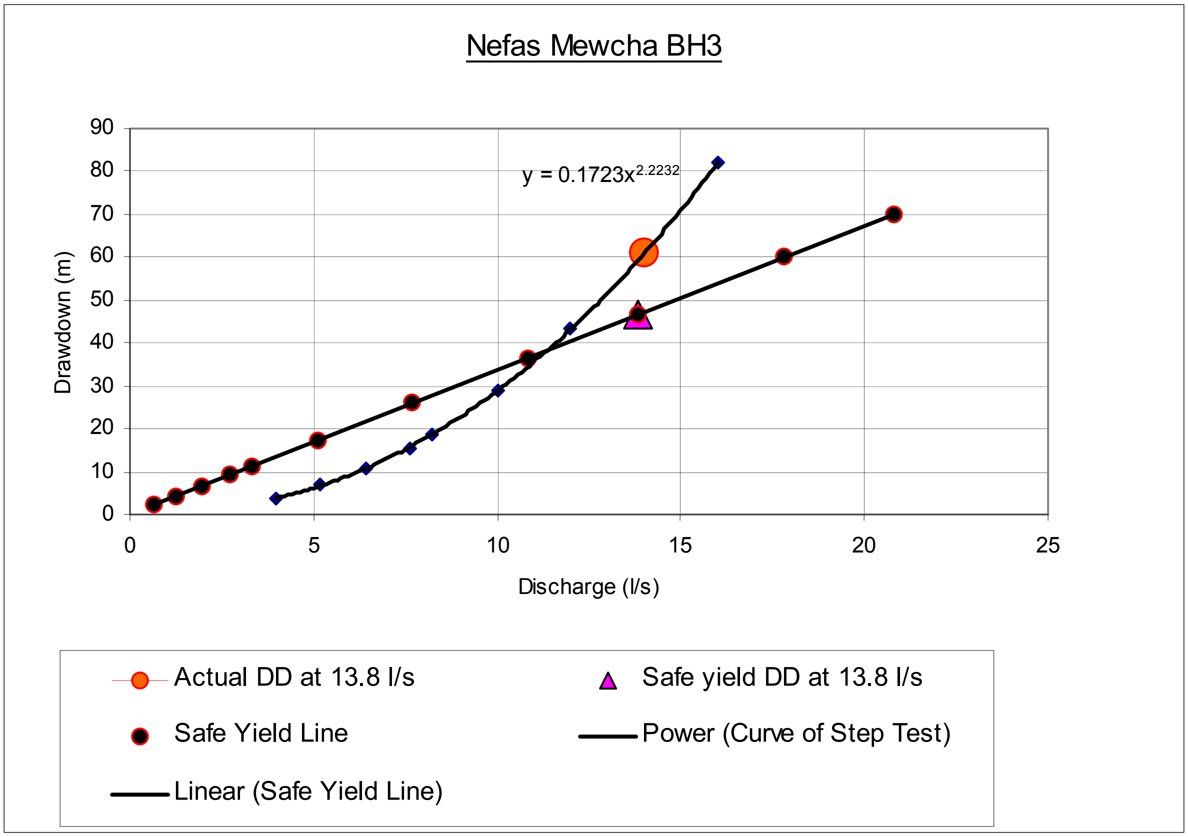

Figure 9. Figure showing the difference between actual well behavior and the use of safe yield equation (data from Nefas Mewcha BH3 Northern Ethiopia)

Table 1. Summary of data used to plot curves on figure 9.

Data based on the curve of Step test		Discharge based on Safe yield Equation	
Discharge L/s	Drawdown (m)	Design Drawdown= 0.6*Add	Discharge (Q) =SC*Add
4.00	3.68	2.21	0.66
5.20	6.93	4.16	1.24
6.40	10.87	6.52	1.94
7.60	15.17	9.10	2.70
8.20	18.65	11.19	3.32
10.00	28.82	17.29	5.14
12.00	43.22	25.93	7.70
14.00	60.88	36.53	10.85
16.00	81.92	46.50	13.81
		60.00	17.82
Sc From constant test = 0.297		70.00	20.79

Most drilling results report indicate as the safe yield of the well just by calculating the yield using the design yield formula based on the specific capacity obtained from constant discharge tests. Because of limitation in the pump capacity constant testes are conducted for longer duration at the maximum out put of the pump. Some wells do not show significant drawdown while tested with a single-discharge rate and give higher specific capacity. Therefore, by taking this value calculating a design yield beyond the well is actually test pumped, leads to erroneous conclusion. For example the boreholes in Akaki Well field of Addis Ababa city are pumped with a discharge rate of 87 l/s. Most of the wells have no drawdown. The maximum drawdown obtained with one well is about 6 m giving a specific capacity of 14.6 l/s/m. The borehole has 30 m available head (the difference between the top of screen and the static water level). If one takes this value and calculates the design yield considering minimum safety factor of 60 % the well will have to be designed for a discharge rate of 263 l/s which is almost 3 times over the rate at which the well is tested. If some one designs a well for this discharge he has to design large diameter well, a very high capacity pump. But after implementation if the well doesn't produce the extrapolated value the whole cost incurred and the time spent would be a great loss.

Some fractured aquifers do not show significant draw down at lower rate of pumping, but with slight increase in the pumping rate they give higher drawdown. Therefore, with a constant discharge test using lower capacity pumps sufficient drawdown may not be created in the well, and this does not mean that the well would behave proportional to the pumping rate even pumped at a significantly higher discharge rates.

When and how to Use the Safe yield method

Wells designed for continues pumping

These types of wells are mostly designed for supply of towns or cities. They can be pumped continuously even over 24 hours. In such types of pumping the pumping rate is designed in order not to create excessive drawdown in the well to reach the pump or the screen position.

As shown above drawdown does not proportionally increase with increase of pumping rate. The best way to understand the behavior of the well is to conduct step drawdown tests up to the maximum possible pumping rate. From this test the point at which the change from laminar to turbulent flow can be estimated. Once this point is known the well can be test pumped with a constant discharge rate within the laminar flow condition for longer period, if possible 72 hours to a week. In such condition the safe yield formula can be used to specify the design discharge for the desired available head using the specific capacity obtained from the long period test pumping.

In the absence of step test result one should not design the well for a discharge rate over the actually observed discharge and drawdown from the constant test result. In this condition the safe yield formula can be used to specify the discharge of the well for a lower drawdown than the observed drawdown. Never use the design formula for a discharge rate beyond what is determined from the constant discharge test.

Wells designed for intermittent pumping

Mostly rural water supply boreholes are pumped intermittently between 4 to 6 hours in a day, which is 2 hours or 3 hours continuous pumping. For such types of wells Some times it may be important to pump the well at higher discharge rate for a shorter duration and then stop pumping to allow it to recover. This can be done taking into account the drawdown created with different discharge rates of step tests.

In the absence of step discharge test, the constant discharge test result can be used without extrapolating beyond the observed discharge and drawdown. Some times the pumps available for permanent installation in the borehole may have high capacity than the well is tested and even beyond the wells sustainable capacity. In this case it would be necessary to conduct test pumping using the pump to be permanently installed in the well and an appropriate pumping rate and duration can be selected.

Some times even rural water supply would require continuous pumping for longer hours such us up to 20 hours pumping depending on the water demand of the area. In this condition use the data both from the step and constant discharge tests to design the sustainable pumping rate. In the absence of step tests do not extrapolate the discharge beyond what is observed from the constant test. The design yield formula can be used for a discharge rate within what is observed from the constant discharge test.

Conclusion

The design yield (safe yield) equation is a linear equation, which does not actually represent the behavior of the well during pumping. Using it for extrapolating pumping rate beyond what is actually observed have risks of over designing the well.

The best method to design a well is conducting both constant and step tests. The step test should be conducted at a discharge rate up to the maximum possible.

The design yield formula has limited importance than it is currently being used in the country. It is only applicable for designing the discharge of the well within actually observed values. Never use the design yield formula for a discharge beyond the observed discharge and drawdown.