SESSION 16

ECONOMIC DESIGN OF WELLS

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1. Introduction

The cost of water from a well depends upon **the capital invested** and **the annual recurring costs**. A large part of the recurring element derives from the cost of pumping. Capital costs and pumping costs are interdependent to the degree that the design of the well affects the drawdown and thus the pumping cost. For example, a short screen section will produce a larger drawdown than a long screen for a given discharge. Thus saving in capital is offset by increased pumping costs. Similarly a screen of small diameter produces large entry and upflow losses and again increasede recurring costs. For each chosen design parameter there is an optimum solution for least cost. This session is concerned with the determination of such least cost solutions.

1. Introduction

The principle of the analysis is to produce an equation representing the total cost in terms of a single design parameter and to apply a discount cash flow procedure to calculate the present value. Differentiation of the present value expression with respect to the chosen parameter leads to the determination of the optimum value of that parameter for minimum cost.

2. Principles of Economic Well Design

In designing wells, the objective is **to produce water for the least cost**. In economic analysis, a distinction is normally made between **economic and financial cost concepts** and the general principles outlined in this session are valid for either approach. The cost of drilling and operating a well comprises the capital investment plus annual recurring costs. A conventional discounting procedure can be applied to these costs and a present value obtained. It is this present value which must be minimized to obtain the optimum well design.

2. Principles of Economic Well Design

Capital and recurring costs of wells are closely interdependent because in a deep aquifer any changes in well screen length, in diameter, or in discharge may affect the drawdown in a well and thus the total head through which the water must be pumped. For example, large diameter well screen and liner may substantially reduce pipe losses. Thus, an increase in capital cost will reduce pumping head and hence pumping costs. Somewhere there is an optimum.

2. Principles of Economic Well Design

The costs of a well can be presented as a functions of the various parameters involved, (see **Figure 2.1**):

$$\text{Capital cost} \qquad C = F_1\left(D, W, \phi, s_w\right)$$

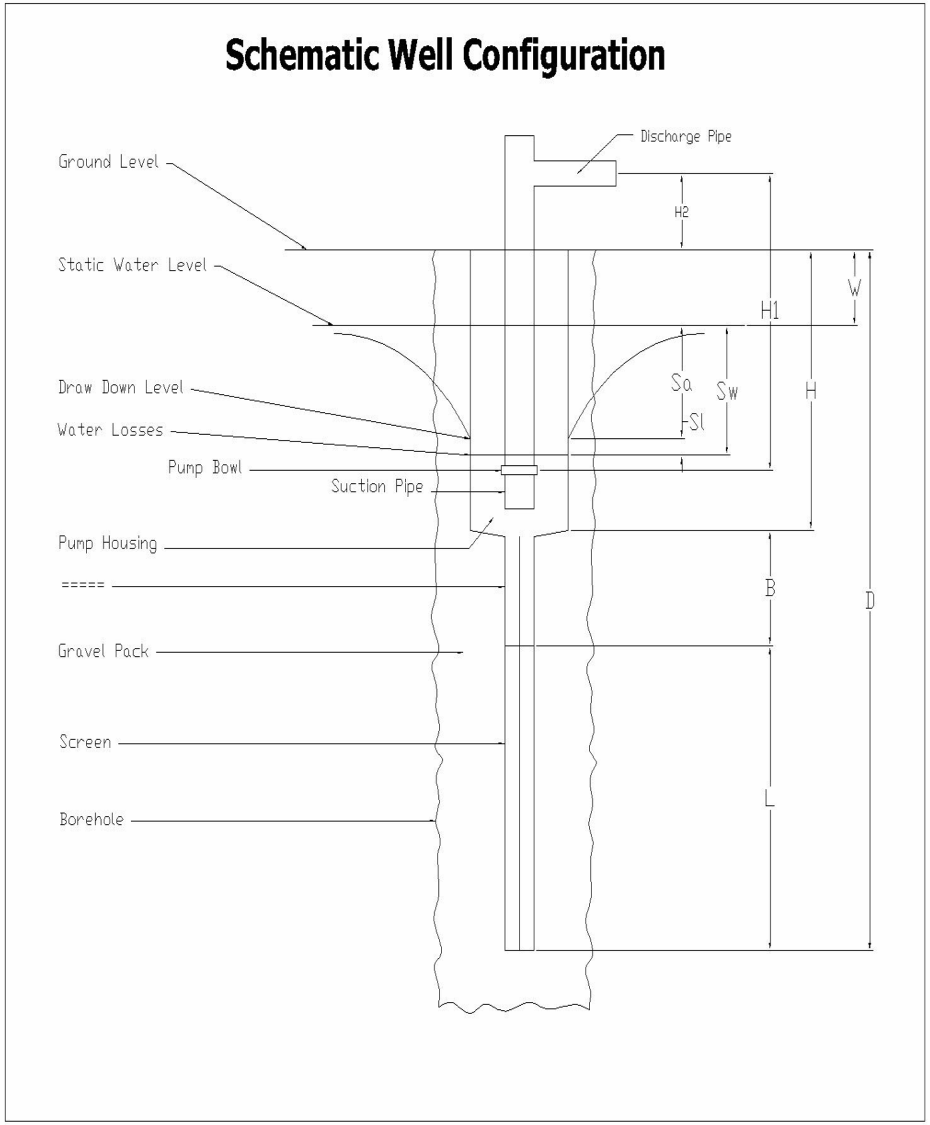
$$\text{Recurring cost} \quad c = F_2\left(H_2, Q, s_w, m, t\right)$$

where,

D total depth of well
W depth of water table or piezometric surface below ground level
Φ non-specific diameter
s_w drawdown of water level in the well
H_2 distance between ground level and discharge pipe
Q discharge
m maintenance cost
t hours pumped per year

2. Principles of Economic Well Design

Figure 2.1 Schematic well configuration



2. Principles of Economic Well Design

If c_1, c_2, ... , c_n represent recurring costs in the years 1 to n, then:

$$\text{Present value } PV = C + c_1 f_1 + c_2 f_2 + \ldots + c_n f_n$$

$$f_n = \frac{1}{\left(1 + \frac{r}{100}\right)^n}$$

where,

n is the life of the well in years,
$\boldsymbol{f_n}$ is the discount factor as shown,
r is the interest rate percent per annum. Usually values for *f* are taken from standard tables.

2. Principles of Economic Well Design

By partially differentiating the PV with respect to any of the variables and equating to zero, the optimum value of each variable can be determined for minimum cost.

Thus, **d PV/d L = 0 would give the optimum screen length for a fixed discharge, diameter, interest rate, and time of pumping.** By examining the various partial differentials in turn the well design can be optimized.

3. Inter-relationships Between The Variables

Solutions to the equations depend upon the relation-ships between **Q, s_w, d** (diameter of flow conduit "pipe or casing") and **L** (length of screen). These relationships are entirely empirical and have been derived from a large number of well tests.

For a uniform aquifer, which is deep compared with all likely screen length. The drawdown in the well **(s_w)** is the same as the drawdown in the aquifer **(s_a),** for wells of zero well losses, and at equilibrium:

$$s_w = \frac{AQ}{KL}$$

3. Inter-relationships Between The Variables

To account for the well loss **(s_l)**, the relationship derived by Rorabaugh (1953) gives:

$$s_w = BQ + CQ^n$$

$$or$$

$$s_w = s_a + s_l$$

in these equations, **A**, **B**, and **C** are constants and **K** is the hydraulic conductivity of the aquifer. Well losses are presented by the term **CQ^n** and can be broken down further into screen entrance losses and pipe losses in the well.

For most practical cases of wells correctly designed, entrance losses should be negligible and may be disregarded.

3. Inter-relationships Between The Variables

The manner in which costs relate to the variable parameters is not easy to obtain.

For example, while it is fairly easy to abstract well costs from a contractor’s tender, it is more difficult to determine just how these costs might change if the diameter of the well was increased; heavier equipment might be required than that assumed in pricing an existing tender.

Similarly, to obtain a complete matrix of pump price variations with different discharges, pump settings, and total delivery heads is more than many manufacturers are willing to provide.

4. Calculation Of The Present Value (PV)

To calculate PV, one should follow the following procedures:

1. It is necessary to reduce the number of variables in the capital cost.

$$s_w = \frac{1.25Q}{KL}$$

The dimensional relationships used in the simplification may be derived from **Figure 2.1** and are for a particular case:

$$H_1 = W + H_2 + 1.25s_w$$
$$H = H_1 - H_2 + 3.6$$
$$D = H + B + L$$

4. Calculation Of The Present Value (PV)

These allow for:

- ✓ the mean drawdown throughout the well's life to be 25% greater than the initial value,
- ✓ a pump housing length **H** to induce an extra **3.6 m (12 ft)** below the pump bowl, **3 m (10 ft)** for the length of suction pipe and **0.61 m (2 ft)** for the end clearance.

2. The capital cost must be derived from the collected and estimated data.
3. The recurring costs "running costs" must be derived from the collected and estimated data.

4. Calculation Of The Present Value (PV)

4. Note, when the running cost is the same every year, it can be discounted to present value by using a single factor which is dependent on the life of the project and the discount rate adopted. **For example**, if a life of 20 years is used and an interest rate of 10%, then the **discount factor** is **f =8.5136**, and the present value of the total cost is **PV=C+8.5136c**. since,

$$Running\ cost = c_1 f_1 + c_2 f_2 + \ldots + c_n f_n$$

$$but\ in\ this\ case \quad c_1 = c_2 = \ldots = c_n$$

$$so, running\ cost = c\left(f_1 + f_2 + \ldots + f_n\right) = c\, f$$

$$f_n = \frac{1}{\left(1 + \frac{r}{100}\right)^n}$$

And, $\mathbf{f_1}$= 1/1.1^1 = 0.909, $\mathbf{f_2}$= 1/1.1^2= 0.826, $\mathbf{f_3}$=1/1.1^3= 0.751, $\mathbf{f_4}$ = 0.683, ... , $\mathbf{f_{20}}$= 1/1.1^{20}=0.147.

So, **discount factor (f)** = f_1+f_2+ ... + f_{20} = 8.5136

4. Calculation Of The Present Value (PV)

5. Now, the total cost can be determined, which is the sum of capital costs and running costs.

$$\text{Present value } PV = C + c_1 f_1 + c_2 f_2 + \ldots + c_n f_n$$

5. Optimum Screen Length

For minimum present value, the partial differential of present value with respect to screen length must equal to zero (see **Figure 4.1**):

$$\mathbf{dPV/dL = 0}$$

The method outlined above only gives the optimum for minimum overall cost, but it is interesting to examine the nature of that minimum and to test the sensitivity of the result to changes in the assumptions.

6. Optimum Discharge

By a similar process to that illustrated previously, the optimum discharge can be determined from the present value equation. But because the least cost in terms of Q occurs when the well is not pumped at all, it is necessary to consider the problem in terms of least cost of water per unit of discharge. Thus dividing the present value by the well capacity, as shown below:

$$V = \frac{PV}{Q}$$

$$then \quad ,$$

$$\frac{dV}{dQ} = 0$$

4. Calculation Of The Present Value (PV)

Figure 4.1 Derivation of optimum screen length